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GROUND WATER CONTAMINATION. PROCEEDINGS OF THE 1961 SYMPOSIUM HELD IN CINCINNATI, OHIO, 5-7 APRIL 1961

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1961

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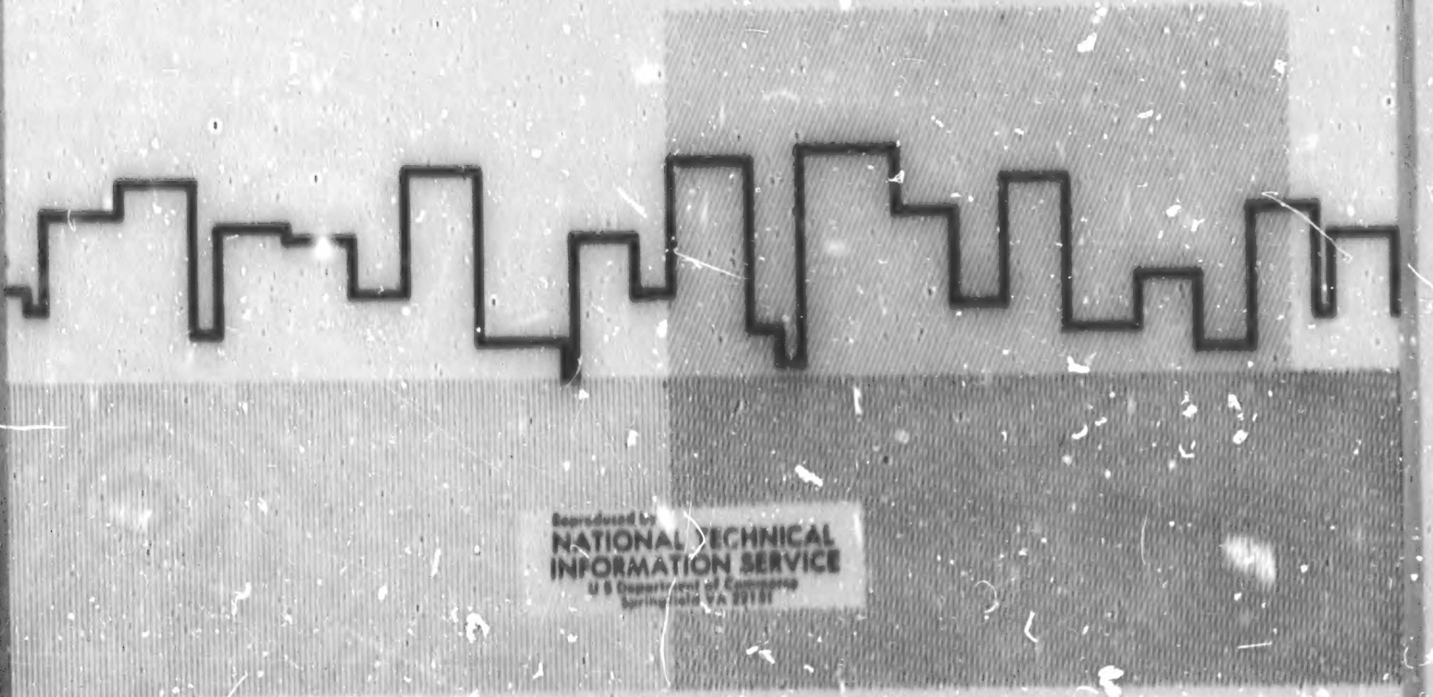
GROUND WATER CONTAMINATION



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U.S. DEPARTMENT OF HEALTH,
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GROUND WATER CONTAMINATION

Proceedings of the 1961 Symposium

April 5-7, 1961
Cincinnati, Ohio

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Water Supply and Pollution Control

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

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EDITORIAL NOTE

The papers in this volume were prepared for oral delivery in the Symposium and necessarily have been edited to meet publication standards of the Public Health Service. Every effort has been made to present accurately the full data and the original views and meaning intended by the authors. Records of informal discussions have been summarized by technical reviewers so that the key points of those could also be included in these proceedings.

The Robert A. Taft Sanitary Engineering Center is a national laboratory of the Public Health Service for research, training, and technical consultation in problems of water and waste treatment, milk and food safety, air pollution control, and radiological health. Its technical reports and papers are available without charge to professional users in government, education, and industry. Lists of publications in selected fields may be obtained on request to the Director, Robert A. Taft, Sanitary Engineering Center, Public Health Service, Cincinnati 26, Ohio.

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GROUND WATER CONTAMINATION

SYMPOSIUM OBJECTIVES

H. Hanson, Director,
Sanitary Engineering Center, PHS

This is a period of history characterized more by questions than by answers, and we fully expect that this Symposium will be no exception to this situation. From an elementary standpoint, we are gathered here because the ground water resource is important as a source of water for home, for municipility, for industry, and for agriculture. Many of our public supplies in this country come from underground sources; wherever possible, individual homes not served by public systems use this resource. In some places the underground is the only satisfactory storage site for water, and its value, of course, can be reduced by pollution.

The pollution of ground water is insidious. It appears belatedly and often is not recognized until a considerable area has been affected. Once an aquifer is polluted, a very long time may be required to clean it up, even after the source of pollution is removed. We know that the soil and aquifer materials have remarkable capacity for removing some contaminants, and we also know something of the limitations in this regard. It is important that we develop knowledge that will permit continued use of ground water without avoidable damage to its quality, but at the same time we must permit proper use of soil as a waste disposal medium. Further, we need to develop the necessary legal and administrative mechanisms to accomplish this joint usage.

The Public Health Service has for a long time been interested in solving problems of ground water pollution. Some of you may be familiar with the early work of Stiles and Crohurst, one of the pioneer studies on bacterial travel underground. Public health agencies in the past were concerned primarily with biological contamination of ground water, but in recent years we have been forced to turn our attention also to problems of chemical contamination.

Several recent developments have brought about an increased interest in the presentation of good ground water quality. Among these are developments that I am sure are familiar to most of you—the rapid suburban growth with the accompanying increased use of soil disposal systems for households; the increased use of lagoons, oxidation ponds, spray irrigation, and other methods involving applications of wastes to soil; the increased production and use of insecticides and ovicides in the control of pests; the increased production and use of other relatively stable synthetic organic compounds that find their way into water supplied to the soil; the increased salt water intrusion into coastal aquifers; and the growth of the atomic energy industry with its special waste disposal problems.

In recent years the number of incidents of ground water pollution has increased markedly, and as a result the amount of research activity related to ground water quality problems has increased, although I would not begin to venture that the research and study are yet nearly in proportion to the size of the problem. Through past studies a great deal has been learned, but at the same time the vastness of our ignorance has become even more apparent. Not only technical but administrative problems are in need of solution.

About a year ago it seemed to us that there was a sufficiently large group of people interested in the problems of ground water quality and ground water contamination to warrant a get-together to discuss problems of mutual interest. Expectations at that time were for perhaps 50 or 60 people; indeed, we did not expect that 300 or more would convene for 3 days of discussion. We did believe the group would want to discuss experiences with ground water contamination, review the methods available for coping with some of these problems, explore our present knowledge concerning the travel of contaminants in underground waters, and determine what should be done to provide the knowledge and ability to control problems that have arisen. These activities are set forth as the objectives of our Symposium.

It is most gratifying to see the size of the group that has come together here, and it is particularly gratifying to see the number and variety of professional and scientific interests represented. We hope you will find the meeting instructive and profitable, and that the discussions, formal and informal, will be of value in increasing our national ability to deal with ground water contamination problems.

In a meeting of this sort it is obviously not possible to cover all aspects of the subject. You will notice that our program contains no papers on salt water intrusion and radioactive waste disposal. This is not because these matters are not of importance but because they recently have been the subjects of other meetings.

It occurs to me that as you proceed with your deliberations you may wish to give some thought to this Symposium as the beginning of an activity parallel to that in the field of oceanography. I am sure that most of you are aware of the tremendous surge of emphasis on oceanography in the last year or two, the work of the National Academy of Sciences Committee and the 10-year national program on all phases of oceanography (TENOC) that has been developed by this committee. This program has been reviewed by the President's Science Advisory Council, and great impetus has been given to oceanography through this special effort by technical people interested in the field. It may be that as we probe beneath the surface of the ground we will decide that a similarly organized national effort is warranted in our research also, and we may wind up having our own small "TENOC" in the field of the underground, and indeed we may someday have our own "Mohole."

SESSION 1

HYDROGEOLOGICAL ASPECTS OF GROUND WATER CONTAMINATION

Chairman: H. A. Swenson

Geologic Controls Related to Ground Water Contamination, P.E. LaMoreaux and G.D. DeBuchananne . . . Page 3

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GEOLOGIC CONTROLS RELATED TO GROUND WATER CONTAMINATION

G. D. DeBuchananne and
P. E. LaMoreaux, U.S. Geological Survey

Ground water, one of the Nation's most valuable natural resources, is defined as that part of the subsurface water in the zone of saturation. Inasmuch as the zone of saturation lies in the rocks and other earth materials below the land surface, the geology of a particular area has a tremendous influence on the occurrence of water and its movement through the area. Obviously then, the geology determines to a considerable extent what happens to any contaminant that may be introduced into the habitat of the ground water.

Ground water is one phase of the hydrologic cycle. The hydrologic cycle consists basically of precipitation, runoff (both direct and ground water), and evapotranspiration; and then the cycle starts again with precipitation. Each of the three basic parts of the cycle can be subdivided, so that we get such things as snow, base flow, soil moisture, and transpiration. Ground water is a phase of runoff that results from the absorption of moisture at the earth's surface, downward movement of the moisture through the zone of aeration to the zone of saturation, and then lateral movement under the influence of gravity to a point of natural or artificial discharge.

Contaminated ground water or a liquid contaminant generally could be expected to travel through the zone of aeration and the zone of saturation to a point of discharge along the same path as uncontaminated ground water. The same geologic factors that control the movement of uncontaminated ground water also control the movement of contaminated ground water. Exceptions to such a generalization occur when the contaminant changes the density and/or the viscosity of the ground water or when chemical factors, such as the ion-exchange phenomenon, become involved.

Contamination of ground water can occur from a point or line source in a recharge area such as a contaminated surface pond or stream, accidentally spilled contaminating material, or planned surface-storage facilities for leachable contaminated solids. Such contamination will, like uncontaminated moisture, move downward through the zone of aeration to the zone of saturation and then laterally toward points of discharge. The natural direction and rate of such movement are largely dependent upon the geology of the aquifier, but in some cases artificial controls can be used to alter both the rate and direction of movement. Because of the dispersion and slow rate of ground water movement, the artificial controls have to affect a quantity of fluid many times that of the contamination.

In addition to contamination of ground water at a point of recharge, it is possible for a contaminant, by intent or accident, to be injected into the zone of saturation through a disposal well or to be induced to enter a heavily pumped aquifer that has hydraulic connection with nonpotable waters. In such cases also, the contaminated water follows the same paths as uncontaminated water.

In this discussion of ground water contamination, we are primarily interested in the geologic controls that affect ground water movements, from the recharge areas, through the zone of saturation, where the water is temporarily stored, and finally in the discharge areas, where the water reaches surface streams or the atmosphere. Geology affords the framework for ground water; it includes the stratigraphy and structure of the rock formations, which together make up the intricate ground water system.

Geologic factors relate chiefly to geologic formations and their water-bearing properties, and hydrologic factors relate to the movement of water in the formations. The permeability of the formations, which affects the movement of the water, is the result of the geologic agencies that through long ages have altered and formed the rocks, developing their water-bearing properties.

The interstices in rocks are the open spaces in which the water occurs and through which it moves. They differ widely in size, shape, arrangement, and aggregate volume. The openings through which water moves range in size from huge limestone caverns and lava tubes, through all gradations, to the minute pores in clay. Even smaller openings of molecular dimensions are of significance in relation to adsorption phenomena. The interstices are generally irregular in shape, but different types of irregularities are characteristic of rocks of different kinds.

Interstices of the rocks can be grouped into two major classes: primary, or original, interstices that date back to the formation of the rock and the secondary interstices, such as joints, fissures, and solution passages, that developed later. Generally, the primary interstices have been altered by solution, cementation, recrystallization, or other processes.

Water and any attendant contaminant in unconsolidated materials move through the interstices. Accordingly, a clean, coarse gravel is the most productive unconsolidated water-bearing material. It may not be as effective, however, as clayey sand in absorbing and adsorbing a contaminant in the water. Next to gravel as a water-bearing material comes clean, coarse sand, then progressively poorer materials ranging downward to very fine sand and silt and heterogeneous mixtures of fine and coarse particles such as those found in glacial till.

The consolidated rocks, those formed by solidification of molten igneous rock and those developed from unconsolidated sedimentary deposits through pressure, cementation, and recrystallization, are commonly broken into blocks and contain most of their water in joint cracks. Less thoroughly cemented sandstones yield most of their water from pores and are among the most productive of the consolidated rocks. Also, among the most productive formations are cavernous limestones, as found in Florida and southeastern Georgia. Other highly productive rocks include limestone with joints and fractures and basaltic lava with joint cracks that resulted from the rapid cooling of the molten lava. The basaltic lava also has cavernous zones that resulted from the crusting over of broken rock.

Rocks that do not yield water freely, but will furnish water where better aquifers are lacking, include fine-grained and poorly assorted unconsolidated deposits and jointed crystalline rocks such as granite.

The earth's crust consists of layers, or strata, of rocks of various kinds one upon another and underlain by massive or foliated bodies of rocks. Sedimentary rocks and some igneous and metamorphic rocks are usually stratified, whereas rocks that represent solidified magma that was intruded into the stratified rocks generally are massive.

A geologic formation is a body of rock that is large enough in size and consistent enough in type to be mapped. Formations of stratified rocks range from a few feet to hundreds of feet in thickness and may cover hundreds of thousands of square miles, at the land surface or beneath other formations. Geologic formations differ from one another in their water-bearing characteristics, and there are also likely to be important differences in the same formation at different depth horizons and locations.

Most sedimentary formations consist of sheets or layers of rocks that are very thin in comparison with their areal extent. For example, the well-known St. Peter sandstone in the central part of the country has an average thickness of about 100 feet but covers an area of at least 300,000 square miles, extending from Minnesota and Michigan southward to Tennessee.

Stratification of a formation is of great importance in the occurrence and movement of ground water. Aquifers interbedded with less permeable formations constitute the classical artesian system, but the minute stratification within a formation itself also controls ground water movement. Such stratification can be helpful or harmful in problems of ground water contamination.

Sedimentary formations commonly exhibit gradational changes, both horizontal and vertical, in the size and character of the material deposited. Of the material deposited in bodies of water, the coarser, cleaner fragments are deposited close to shore, whereas the fine, silty material is carried outward and deposited in deeper water. Such gradations, or facies changes, in water-bearing formations determine permeability, which affects the occurrence and movement of water through the material.

Most geologic formations have some degree of inclination. Slight dips may be the result of deposition in a sloping position or of deformation after deposition. Steep dips, however, are nearly always the result of deformation. Diastrophic movements of the earth's crust may be so slight that the tilting of the strata may be only a few feet per mile, or it may be so great that the strata are tilted into a vertical position or even overturned. The amount of tilting, folding, and warping may have a marked influence on the movement of contaminated ground water within the affected formations. Only by surface and subsurface geological correlations can the configuration of a formation and its control of ground water movement be ascertained.

In most regions there are two or more series of rocks separated from one another by unconformities. An unconformity is a surface of erosion or nondeposition that separates younger rocks from older rocks. The erosional surface can be developed on horizontal, tilted, or folded strata and may be smooth or quite irregular. In some cases the unconformity itself has been deformed by later folding that complicates the interpretation of the subsurface geology. Extensive unconformities are very common structural features and have very important effects on the occurrence of ground water. Aquifers in the upper or the lower series may be controlled by intervening unconformities.

A joint is a natural rock fracture that has developed without movement of the adjacent blocks. Joints are characteristic of hard, brittle rocks, such as granite, limestone, and sandstone, but not of plastic and unconsolidated materials, such as clay and soft shale. Joints result chiefly from compression during earth movement and from rock shrinkage caused by drying of sediments or cooling of igneous rocks. These joints may be tight cracks or wide fissures, less than an inch apart or several feet apart. They differ in their lateral persistence and in the depth to which they extend. Joints are among the most important water-bearing openings and, as such, are another geologic control in the occurrence and movement of ground water.

If movement or slippage has occurred on opposite sides of a fracture so that the blocks of rock are displaced with reference to each other, the fracture is called a fault. A normal fault results where one block simply drops down alongside another, and a reverse, or thrust, fault where one block or sheet of rock is pushed over another. Large faults that extend long distances and have substantial displacement may have great influence on the occurrence and circulation of ground water.

In some places, instead of a single sharp fault or fracture, there is a fault zone of shattered rock called fault breccia. Such zones commonly represent a large total displacement of the rocks on either side of the zone and afford a good water passage. Perhaps the most important function of faults in relation to ground water is that of conduits leading from deep sources of water to the surface or to a permeable overlying zone. Oftentimes, however, faults are filled with gouge, i.e., powdered rock, that was formed as the blocks rubbed against each other. Also, the fault may be filled with cemented material deposited by ground water, and this material is generally impermeable, making the fault a barrier instead of a conduit for water movement. Some well fields are divided so effectively by fault barriers that pumping a well on one side of the fault will not affect wells only a few feet away on the other side of the fault. Also, the many oil pools that have accumulated against such faults indicate the effectiveness of such barriers.

Of the massive igneous rocks, the extrusive and intrusive rocks differ markedly in their water-bearing character. They differ not only in porosity and water-yielding capacities but also in those structural features that control the occurrence and behavior of ground water.

Intrusive rocks generally consist of massive bodies that extend downward to their source, whereas most extrusive rocks were laid in layers that range in thickness from a few feet to several hundred feet. In some places the total thickness of the layers of extrusive rocks may reach thousands of feet, e.g., the basalt flows in the Snake Plain of Idaho and the Columbia Basin in Washington. Generally, only little water occurs at depth in the massive intrusive rocks; however, small supplies can be found in decomposed parts or in joints. In an extrusive rock formation a solid layer may lie over a permeable zone that contains water. The extrusive lava rocks frequently have different water horizons that resemble those of sedimentary sequences. Very commonly, a permeable zone is found in basalt where the clinkery top of one flow was covered, but not filled in completely, by an overlying flow.

The topography of the land surface also has a very important influence on ground water conditions. In flat-lying land, not bordered by high land and not having an outlet in the form of a stream cut deeply into the plain, the lowlands tend to become filled with water and circulation is slow. Under these conditions, the dissolved materials tend to accumulate as water is lost and highly mineralized water results. In hilly country, on the other hand, the water percolates rapidly downward and is discharged at a lower elevation where the aquifer is exposed at the surface. The active flow of ground water tends to remove the soluble material from the aquifer, thereby providing an environment for ground water of good quality. Obviously, contamination introduced into the poorly drained flat-lying land may remain for a long time, whereas in the hilly country it would be flushed out rapidly. Rapid flushing is not always desirable, however, since contaminants may be moved to a stream where they can travel fast and far.

Geology exercises a dominant control over the occurrence and movement of ground water. If a contaminant is released to the natural environment, the extent of its effect on ground water depends on the geologic factors that affect the movement of the water and the capacity of rock materials to absorb and adsorb the contaminant. Contaminated ground water is subject to the same physical controls as pure water, and therefore geology is a dominant factor in ground water contamination.

HYDROLOGIC FACTORS PERTINENT TO GROUND WATER CONTAMINATION *

R. H. Brown, U. S. Geological Survey

In 1960 Graham Walton (3) presented data concerning contamination, by sewage or other man-made wastes, of surface and underground waters. The circumstances attending the reported incidents of contamination, especially those involving groundwater supplies, have aided materially in the choice of a few principles and ideas that will identify the role of some significant hydrologic factors in the underground movement of fluid wastes.

Walton's discussion of ground water contamination refers often to physical settings into which fluid wastes are discharged at or near the land surface into cesspools, tile-drain fields, and holding ponds. Furthermore, most reported instances of ground water contamination have taken place in relatively humid environments east of the Mississippi River, where the depth to ground water is not great, frequently less than 50 feet, and where unconsolidated materials, such as sands, gravels, and clays, are the principal porous media through which the fluids must move. Thus it is convenient to imagine, for this discussion, a field environment somewhat like that idealized in Figure 1, which is a hypothetical cross section through one side of a river valley.

In Figure 1 are: the perennial stream, receiving surface drainage or runoff from the valley slopes; the water table, ranging in depth below the land surface from zero near the stream to about 50 feet and representing the positions at which water would stand in wells; the unsaturated zone, above the water table, where the pore spaces are only partly filled with water; the saturated zone, below the water table, where the pore spaces are filled with water properly called ground water; and a waste-disposal site, near the land surface. Ground water movement, as suggested by the arrows and the slope of the water table, is

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* Publication authorized by the Director, U.S. Geological Survey.

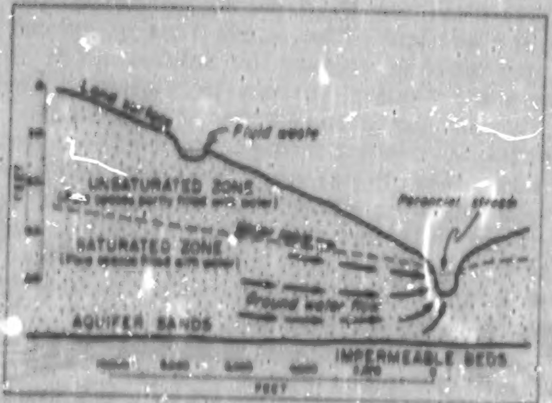
Land surface
Fluid waste
UNSATURATED ZONE
(Pore spaces partly filled with water)
Perennial stream
Water table
SATURATED ZONE
(Pore spaces filled with water)
Ground water flow
AQUIFER SANDS
IMPERMEABLE BEDS
FEET

FIGURE 1. IDEALIZED CROSS SECTION OF A STREAM VALLEY, SHOWING GROUND WATER RESERVOIR

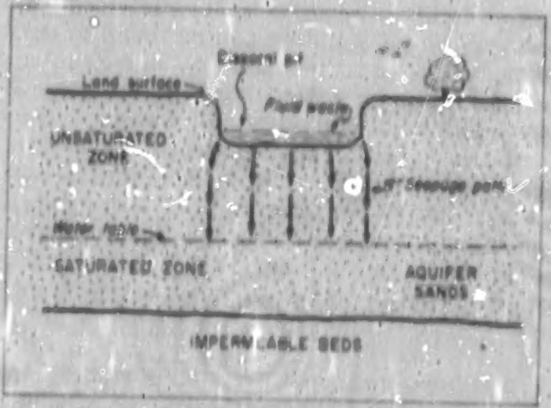
Disposal pit
Land surface
Fluid waste
UNSATURATED ZONE
Seepage path
Water table
SATURATED ZONE
AQUIFER SANDS
IMPERMEABLE BEDS

FIGURE 2. CROSS SECTION OF DISPOSAL PIT, SHOWING SEEPAGE THROUGH AN IDEALIZED UNSATURATED ZONE

toward the river, and thus some natural discharge from the ground water reservoir supports the flow of the stream. The velocity of the ground water movement depends upon the properties of the porous material and the slope of the water table. If a uniform medium sand is assumed; with a water table slope of 10 feet per mile, the average rate of water movement might be of the order of a few inches per day. If the slope were doubled or tripled the rate also would be doubled or tripled.

FLUID MOVEMENT IN THE UNSATURATED ZONE

As may be inferred from Figure 1, the unsaturated zone is an important gateway to the saturated zone, through which precipitation that has infiltrated below the land surface may pass to replenish or recharge the ground water reservoir. If, as it often seems, the unsaturated zone is also the disposal site for various contaminants and wastes, then some knowledge of how fluid moves in this zone is timely.

Figure 2 shows the physical setting at a disposal pond or pit of shallow depth constructed in the unsaturated zone. The porous material for both the saturated and unsaturated zones is assumed to be uniform medium sand. The pit has been in regular operation for many years. As fluid wastes are discharged into the pit, some fluid seeps through the pit bottom and moves toward the water table in the manner suggested by the vertical arrows. In this idealized setting little lateral spreading of the fluid occurs as it moves downward; thus, most of the fluid reaches the water table directly under the pit.

The manner of disposal into the pit greatly affects the time required for the fluid to travel the vertical distance to the water table. Sample computations for two hypothetical types of disposal techniques give some evidence of how much this travel time may vary. If the disposal of contaminant to the seepage pit is assumed to be continuous and steady, in a manner such that the rate of seepage or infiltration is 1/2 inch per day, and no clogging occurs, fluid would never pond in the pit inasmuch as medium sand would accept and transmit the fluid as fast as it arrived. Furthermore, for steady state flow the fluid would move through virtually the entire unsaturated zone at nearly the same rate as the rate of infiltration, 1/2 inch per day. This hypothesis may be given more rigorous expression if it is assumed that when the sand is fully saturated, its permeability, i.e., the rate at which water will move through it under unit hydraulic gradient (1 foot loss in head per foot of flow path) is 70 feet per day. An equation (No. 31, p. 225) discussed by Wyllie and Gardner (6) affords a means for relating the rate of fluid movement, in an unsaturated granular material, to the fraction of pore space filled with the fluid. The cited equation is expressed in the form

$$K_r = \left[\frac{\theta_\ell - \theta_o}{1 - \theta_o}\right]^4 \qquad (1)$$

where

θ_o = irreducible fraction of pore space that will retain liquid against force of gravity

θ_ℓ = fraction of pore space filled with liquid for any given regime of unsaturated flow

K_r = relative permeability, i.e., the ratio of the permeability for the given regime of unsaturated flow to the permeability for saturated flow.

In this example the rate of fluid movement in the unsaturated zone has been assumed to be 1/2 inch per day, or 0.042 foot per day. Thus

$$K_r = \frac{0.042}{70} = 0.0006$$

In equation 1, if θ_o is neglected because of its small value for the assumed medium sand and if the preceding value for K_r is substituted, it follows that

$$\theta_\ell = (0.0006)^{\frac{1}{4}}$$

$$= 0.16$$

This means that the liquid content in the unsaturated zone need only be 16 percent of the pore space to permit fluid movement at a rate of 1/2 inch per day. Experiments with columns of unsaturated material show that, for the slow steady rate of fluid flow assumed here, this percentage can be expected to change very little throughout most of the unsaturated zone. In equation (1), if higher steady rates of waste disposal and seepage through the pit bottom are assumed (i.e., K_r is increased), the corresponding values of θ_ℓ will increase, but because θ_ℓ varies as the fourth root of K_r, it will not increase rapidly. The following tabulation gives results computed for several higher seepage rates:

Seepage, in./day	K_r	θ_ℓ
1	0.0012	0.19
3	0.0036	0.24
6	0.0071	0.29

Instead of the continuous waste disposal assumed for the preceding examples, it might be assumed that the same total amounts of waste are discharged intermittently. This might mean, for example, that in lieu of a continuous and steady discharge rate equivalent to a ponded depth of 4 inches per day there would be a single dumping, every other day, of fluid waste to a ponded depth of 1-1/2 feet in the seepage pit. With the data (p. 228) displayed by Baver (1), used as a guide for fluid movement through an unsaturated soil column with ponding at the surface, it seems reasonable to estimate a value of 0.7 for θ_ℓ. If this is substituted in equation (1) it follows that

$$K_r = (0.7)^4 = 0.24$$

From the definition of K_r, it then follows that the rate of fluid movement through at least part of the unsaturated zone is the product of (0.24) and (70) or about 17 feet per day. This rate for intermittent disposal is to be compared with rates of a few inches or perhaps a few feet per day for the equivalent continuous disposal.

The preceding computations are neither rigorous nor complete; to make them so is beyond the scope of this paper. They may be regarded, however, as approximations pertinent to significant parts of the flow system in the unsaturated zone, indicating the importance of choice of disposal technique in predicting the time required for the fluid waste to traverse the distance to the water table.

Tacit in the discussion thus far are highly idealized physical settings involving unimpeded seepage through the bottom of a disposal pit and a uniform clean medium sand. In practice these idealizations may be greatly modified by factors tending to render the disposal operations more safe.

These factors may include reduction in permeability of the pit bottom by deposition of sediment in or precipitation from the fluid waste and by removal of contaminants by processes of absorption and adsorption as the fluid moves through the porous material. Evaporation and withdrawal of moisture by vegetation from the upper 8 or 10 feet of the unsaturated zone tends to lessen the amount of waste-carrying fluid that traverses the distance to the water table. In the process, however, some wastes or contaminants may be concentrated in this near-land-surface region to be picked up later and carried deeper into the unsaturated zone when natural or artificially induced infiltration of fluids increases and when adsorption sites on the pervious materials at shallow depths are all occupied.

Not all disposals will occupy sites, as assumed here, with uniform medium sand having a permeability with respect to saturated flow of 70 feet per day. Corresponding permeability values for site materials varying from very fine sand or silt to coarse gravel might range from 1 to more than 1000 per day; the implications of the corollary range in rates of fluid movement under unsaturated flow conditions are obvious.

Perhaps more significant than any of the preceding departures from an idealized physical setting, however, is the non-uniform nature of the porous materials at the many places where disposal operations might be practiced. The effect of this factor can be most readily demonstrated by a slight modification of the cross section shown in Figure 2. Such a revised section, in which clay lenses are present in the unsaturated zone, is shown in Figure 3. The permeability of the clay obviously is drastically less than that of the surrounding medium-grained sand. Thus, as fluid moves downward from the disposal pit, as shown by the arrows, its advance is unimpeded until it reaches the first clay lens, which represents a zone of greatly differing permeability. Subsequent events can be read as follows from the details of the sketch: the fluid collects on the upper surface of the clay lens, forming a small perched zone of saturation, and then spreads laterally until it finds a way around the lens; the fluid then continues downward, and the same cycle of events is repeated at each new clay lens encountered. When the fluid arrives at the water table, therefore, it may have traveled a significant distance laterally from the disposal pit. If very many clay lenses are present or if any lenses are of considerable areal extent, little imagination is required to appreciate the possible intricacies and the lateral spread of the fluid wastes as they travel to the water table.

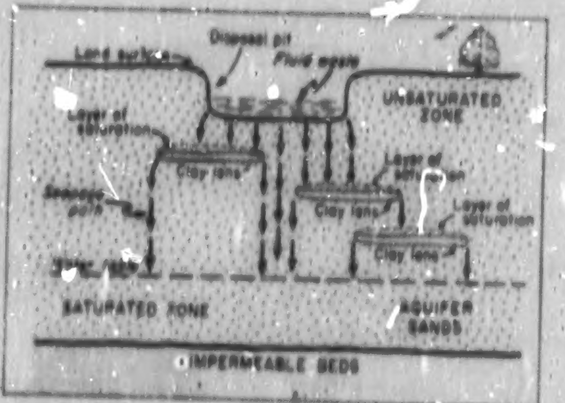

FIGURE 3. CROSS SECTION OF DISPOSAL PIT, SHOWING SEEPAGE THROUGH AN UNSATURATED ZONE OCCUPIED BY CLAY LENSES

The spreading of fluid waste, as depicted in Figure 3, can occur at any boundary between materials of substantially different permeabilities. The phenomenon is readily manifested when the difference in permeabilities is as little as one order of magnitude (10 times), and it matters not whether the fluid is endeavoring to cross a boundary into a region of lower or higher permeability. Predictions of where and how a fluid waste may travel from disposal site to the water table thus require detailed information on the physical characteristics, location, and extent of all pervious and impervious materials in the unsaturated zone.

FLUID MOVEMENT IN THE SATURATED ZONE

Inasmuch as the term ground water is properly applied only to water in the zone of saturation or that available to wells, the whole subject of ground water contamination

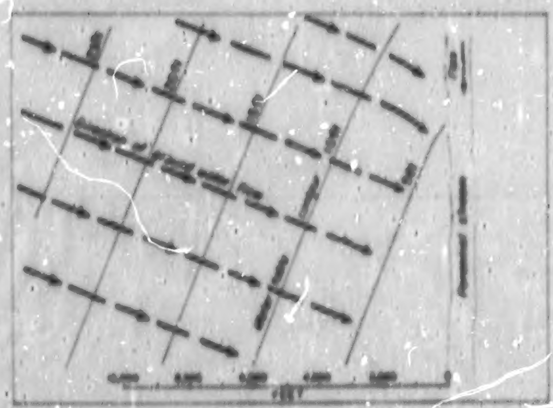

FIGURE 4. WATER TABLE MAP OF AN AQUIFER DISCHARGING INTO A PERENNIAL STREAM

ultimately must focus on the nature of fluid movement in that zone. In the preceding section the manner in which fluid waste might reach the water table was examined, and of interest now are some possible travel routes of the fluid once it has entered the ground water reservoir or aquifer.

A plan view of the idealized homogeneous ground water system shown in Figure 1 might be represented as shown in Figure 4. The contours indicate elevations of the water table in feet above some reference datum; the arrows generalize directions of ground water movement toward the stream. If a contaminant reaches the water table anywhere in the mapped region, it will move with the ground water in a fairly straight or definable path toward the stream. This would be the nature of the movement in ideal homogeneous systems under natural conditions, and therefore it would not be difficult to predict the path the contaminant might follow as well as its positions along the path after successively longer time intervals.

Usually, however, the natural flow system in an aquifer is modified at least locally by domestic, industrial, or municipal wells. In most of the region tributary to the stream (Figure 4), the arrows are essentially parallel to each other. If a well were constructed in this region and pumped at a steady rate, some of the parallel lines representing directions of ground water flow would bend toward the well and the resulting pattern of flow would be as shown in Figure 5. Skibitzke (3) has given a simple relation for expressing the width of the area in a region of parallel flow within which the flow lines will converge upon the well. The relation, for a unit thickness of the aquifer, may be given in the form

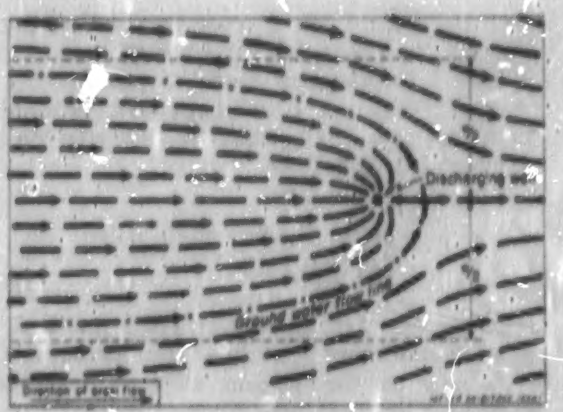

FIGURE 5. FLOW LINES NEAR A DISCHARGING WELL CONSTRUCTED IN A REGION OF PARALLEL GROUND WATER FLOW

$$w = \frac{Q}{PI} \qquad (2)$$

where

w = maximum width of the area of parallel flow within which the ground water will ultimately move to the well

Q = discharge rate per unit length of well bore

P = permeability of the saturated material comprising the aquifer

I = regional hydraulic gradient (head loss per unit length of flow path) under natural flow conditions before wells are introduced.

The dash-dot flow line in Figure 5 encloses the area of diversion of the regional ground water flow to the well. If it is assumed that the natural hydraulic gradient in the direction of ground water flow is 10 feet per mile, that the well discharge per unit length of bore is 1 gallon per minute (or 1440 gallons per day), and that the porous material of the aquifer is a uniform medium sand having a permeability, under unit hydraulic gradient, of 70 feet per day, then, by substitution in equation (2), it follows that

$$w = \frac{(1440/7.48)}{70(10/5280)} = 1450 \text{ feet}$$

This means that upgradient from the well a contaminant that reaches the water table anywhere in the region whose maximum width is 1450 feet and whose general shape is as shown in Figure 5 ultimately will emerge in the well discharge. The converse of this example is also true, i.e., if the well were being used to dispose of liquid waste at the rate of 1 gallon per minute, and the same regional flow data were assumed, the contaminants would enter the aquifer and move away from the well ultimately spreading to a band width of 1450 feet. In either of the preceding examples, if the rate of well discharge or recharge were doubled or tripled, the width w would also be doubled or tripled. Similarly, if changes are postulated in either the permeability of the water-bearing material or in the natural regional hydraulic gradient, the effect on w can be determined by reference to equation (2).

Although the unsaturated zone is an important access route traveled by fluid wastes from various types of disposal operations, ground water reservoirs or aquifers are commonly in direct contact with surface water bodies such as ponds, lakes, and streams that may contain contaminants. The aquifer shown in Figures 1 and 4 is obviously in direct contact with a stream. As drawn, the ground water system discharges into the stream and cannot be contaminated by any wastes carried in the stream; however, situations occur in which a stream feeds or recharges part of an aquifer. A fairly common situation is pictured in Figure 6, which shows a supply well near a stream. As the well is pumped, the water level will decline in the surrounding area, and the ultimate steady state patterns of water table contours and ground water flow lines in the vicinity of the well will be as shown in Figure 6. The patterns as drawn represent an idealized homogeneous aquifer. If the stream shown in Figure 6 is polluted, the water could readily move toward the pumped well and sooner or later appear in the well discharge. Theis (4) developed equations for approximating the percentage of well discharge derived from the stream at different elapsed times after pumping begins. Again, the converse of the preceding example is true, i.e., if the well were used to dispose of liquid waste, the contours in Figure 6 would represent the built-up or mounded configuration of the water table and the arrows denoting directions of ground water flow would be reversed.

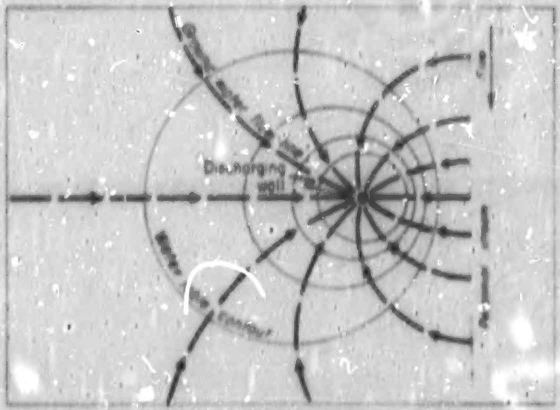

FIGURE 6. FLOW LINES AND WATER TABLE CONTOURS NEAR A DISCHARGING WELL CONSTRUCTED NEAR A STREAM

Brief mention has been made heretofore of wells being used for the disposal of liquid wastes. At a number of places in the east, wells have been used to dispose of industrial wastes and storm runoff from city streets. This introduction of contaminants via a well, directly into the saturated zone, prompts immediate concern for the continued safe use of any nearby supply wells. Two examples from a recent paper by daCosta and Bennett (2) afford some appreciation of the factors controlling the possible interflow between a recharging well and a nearby discharging well, in a region where parallel flow of ground water pre-existed.

The first example concerns a pair of discharging and recharging wells oriented so that a line joining them is parallel to the direction of regional ground water flow, and

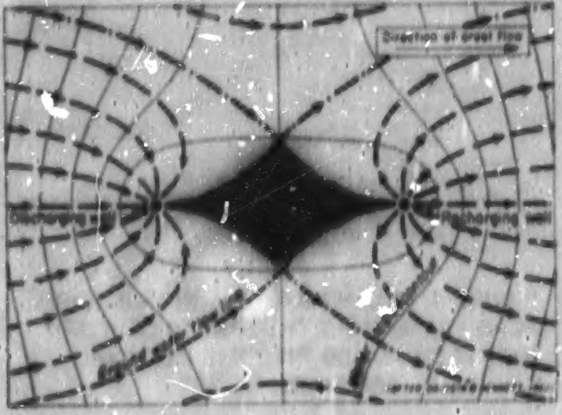

FIGURE 7. FLOW LINES AND WATER TABLE CONTOURS NEAR A PAIR OF RECHARGING AND DISCHARGING WELLS ALIGNED WITH THE REGIONAL FLOW

the recharging well is downgradient from the discharging well. The ultimate steady state configurations of the water table contours and the flow lines around such a pair of wells are shown in Figure 7. Within the shaded area, flow lines that diverge from the recharging or disposal well subsequently converge upon the discharging or supply well. The illustration was drawn under the assumptions that the two wells have operated at the same rates over the same period and that the following critical relation exists.

$$\frac{Q}{\pi a V_0} = 1.27 \qquad (3)$$

where

Q = rate of well discharge, or recharge, per unit length of well bore

a = half the distance between the two wells

V_0 = rate of regional parallel ground water flow.

In determing the relation expressed as equation (3), daCosta and Bennett found that, for all values of the ratio $Q/\pi a V_0$ larger than 1.27, there would be some degree of interflow from the recharge to the discharge well, regardless of their orientation with respect to the natural regional flow. At the critical or limiting value of 1.27, interflow would be zero for only one orientation of a line joining the pair of wells, with respect to the direction of regional flow. For all other orientations, some degree of interflow would occur. For the situation shown in Figure 7, the amount of interflow is about 4 percent of the recharged fluid. The orientation for zero interflow (not illustrated) lies between the orientations shown in Figures 7 and 8. For values less than 1.27, some orientations of the wells will result in interflow and other orientations will ensure no interflow but will overly restrict the allowable rate of well discharge or recharge or the minimum distance between the wells. For the setting illustrated in Figure 7, if it is assumed that the aquifer material is again a uniform medium sand having a permeability of 70 feet per day, under unit hydraulic gradient, and that the regional hydraulic gradient or slope of the water table in the direction of flow is 10 feet per mile, the regional velocity of flow, V_0, is the product of 70 and (10/5280), or 0.13 foot per day. With this value substituted in equation (3), it follows that

$$\frac{Q}{a} = 0.52$$

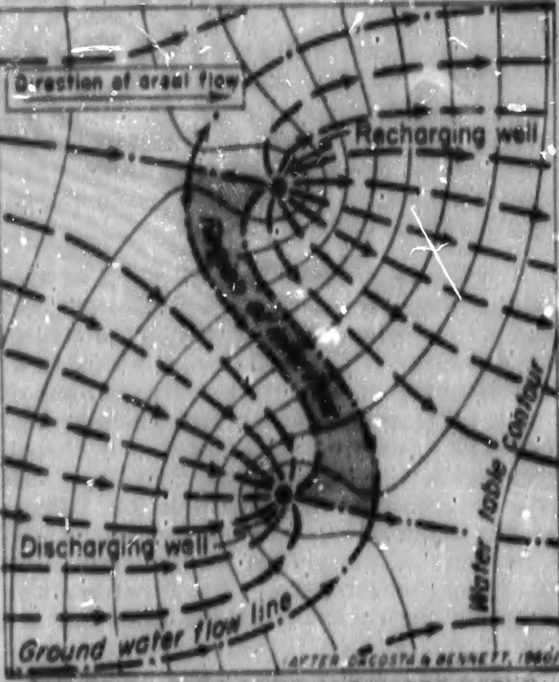

FIGURE 8. FLOW LINES AND WATER TABLE CONTOURS NEAR A PAIR OF RECHARGING AND DISCHARGING WELLS ALIGNED AT RIGHT ANGLES TO THE REGIONAL FLOW

Therefore, if the wells were 400 feet apart ($a = 200$ *ft*), the rate of discharge or recharge would be slightly greater than 1/2 gallon per minute per foot of well bore to develop the flow pattern shown in Figure 7. Other combinations of Q, a, and V_o that would satisfy equation (3) are readily made.

The second example is of a pair of discharging and recharging wells oriented so that a line joining them is at right angles to the direction of regional ground water flow. The ultimate steady state configurations of water table contours and flow lines around the wells are shown in Figure 8. The shaded area again encompasses the flow lines that diverge from the disposal well and subsequently converge upon the supply well. About 9 percent of the recharged (waste) fluid makes up this interflow. The illustration is drawn for the same conditions that were assumed for Figure 7; thus, the relations among Q, a, and V_o may be hypothesized and explored as before.

The preceding discussion of fluid movement in the saturated zone contains many idealizations and assumptions. Nevertheless with appropriate data on the location, extent, and physical properties of water-bearing materials and on the boundaries of the ground water flow system, it is possible to analyze the relative merits of a variety of waste disposal techniques and to describe the probable consequences of each. Thus the hydrologist can contribute effectively to the design of disposal systems that will minimize or eliminate the danger of contaminating those parts of the ground water resource that are already being or may later be developed for beneficial use.

One important factor should be considered briefly. Many aquifers are composed of non-uniform kinds of material, such as sand or gravel. Thus, fine, medium, and coarse sands and gravels, as well as silts and clays, are often present in what may appear to be a meaningless arrangement of lenses and beds. To map the location and extent of each kind of material and to compute how fluid might move through it would be an endless task.

Fortunately, knowledge of erosional and depositional processes aids materially in filling in details between points where observations can feasibly be made. Furthermore, flow experiments with artificial aquifer models (Skibitzke, 1960, oral communication), simulating some of the non-uniform conditions found in nature, reveal that the flow regime is not chaotic. Figure 9 was drawn from a photograph of an aquifer-model experiment. The view simulates a broad expanse of aquifer with steady regional ground water flow from left to right, as shown. Medium sand comprises most of the aquifer, but trending through it are three continuous stringers of much coarser sand in somewhat sinusoidal paths. Where one stringer seems to disappear, it simply dips below the aquifer-model surface to pass beneath the stringers that remain visible. Two different colored dyes, which could represent fluid wastes, are available at wells A and B, to be picked up and carried along by the flowing ground water. Different degrees of shading distinguish the courses taken by the fluids originating at A and B. Although the stringers of higher permeability afford some local preferential paths for flow, the regional movement of ground water sometimes crosses these stringers. Particularly significant, however, is the spreading of dyes or wastes as they traverse the region. The maximum spread appears to be about twice the amplitude of the sinusoidal, highly permeable stringers.

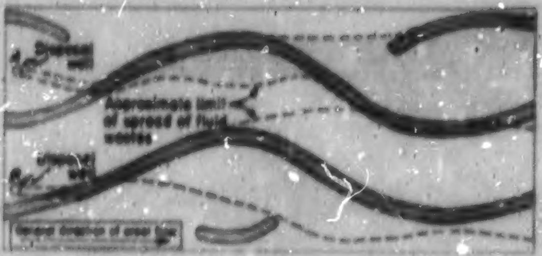

FIGURE 9. PLAN VIEW OF A NON-UNIFORM AQUIFER, SHOWING THE SPREAD OF FLUID WASTES RELEASED INTO THE REGIONAL GROUND WATER FLOW

Only two dimensions of the flow system in the model aquifer appear in the illustration, but spreading similar to that shown occurs also in the third dimension. If representative flow paths could be sketched in perspective, characteristic all three dimensions of the flow regime, it would be seen that considerable intertwining of the flow lines occurs. The implications are obvious with respect to predictions of travel paths for wastes originating at A and B. The hydrologist, therefore, must be able to recognize and describe those features of the local and regional geology that will most significantly affect the flow of ground water.

HYDROLOGIC FACTORS

Up to this point in the discussion, a number of hydrologic factors have been covered inobtrusively. Their brief review, and mention of a few others, will serve as a summary. The discussion has also been limited arbitrarily to environments of unconsolidated or granular porous media. Environments of consolidated rocks, such as granites, sandstones, and limestones, pose additional problems in defining the fluid-flow regimes that involve joint patterns, fracture patterns, solutional openings, and the rock structure.

Infiltration Rate

No attempt has been made to detail the mechanism of infiltration, i.e., the process by which fluids penetrate below the land surface. Common sense argues, however, that the finer the grain of the porous material, the slower the infiltration rate. A slow steady infiltration rate through the bottom of a disposal pit or through the porous material in which a tile drain field is laid could be the most significant insurance for delaying the arrival time of a fluid waste at some unwanted location.

Evaporation and Transpiration

The amount of fluid that might ultimately traverse the unsaturated zone is lessened by the processes of evaporation and transpiration. These processes, often combined into the single term evapotranspiration, account for the discharge to the atmosphere of large proportions of the fluid temporarily retained in the upper 8 or 10 of the unsaturated zone.

Unsaturated Flow

Rigorous mathematical description of fluid movement through the unsaturated zone, where the pore spaces are only partly filled with fluid, is difficult. The movement obviously is strongly related to the rate and manner in which the fluid is first introduced to the zone. Other factors include the amount and geometry of pore space in the porous material, the magnitude and direction of temperature and chemical gradients, and such fluid properties as density, viscosity, and surface tension.

Saturated Flow

Fluid movement in the saturated zone, where the pore spaces are filled with fluid, has been described in many scientific papers and reports. Analysis of the flow regime requires knowledge of the geometry of the ground water system and how it is connected with surface water bodies or sources of recharge, the nature of the porous material with respect to fluid movement through it, and the head distribution.

Permeability

Different kinds of rocks and earth materials resist, to differing degrees, the movement of fluids through them. The range in permeabilities from the tightest clays to the coarsest gravels, in terms of the kind of velocity units used in this paper, exceeds nine orders of magnitude. In many earth materials there are significant variations in permeability with distance and direction. Especially important is the fact that permeability in the vertical direction is commonly much less than in the horizontal direction. This is to be compared with predominantly vertical movement of fluid in the unsaturated zone and horizontal movement in the saturated zone.

Non-Uniformity of Porous Media

Flow in both the unsaturated and the saturated zones can be greatly affected not only by changes in texture within a given kind of porous material but also by the presence in that material of lenses or beds of other kinds of porous material. In alluvial valleys and in areas that were once glaciated, the distribution of different kinds of porous media is random. The analysis of problems of ground water contamination in such environments requires the exercise of the best hydrologic skills.

CONCLUSION

Only a few principles of fluid movement in porous media and a few ground water flow systems of simple geometry have been covered in this brief paper. Many ramifications and extensions can be found in the voluminous literature on the occurrence and movement of ground water. The cited references in particular define segments of the science of ground water hydrology that warrant careful study prior to analysis of situations of actual or potential ground water contamination.

The consequences of ground water contamination can be just as damaging to water users as the pollution of surface streams. In fact it can be argued that the consequences are far more damaging because they persist over much longer periods of time after the contaminating source has been eliminated. It would appear prudent, therefore, to guard against contamination of the ground water resource in the first instance, rather than to engage in long expensive rehabilitation measures after the damage has been done.

REFERENCES

1. Baver, L. D. Soil Physics. John Wiley & Sons, Inc., New York. 1948. Ch. VI.
2. daCosta, J.A., and Bennett, R.R. The Pattern of Flow in the Vicinity of a Recharging and Discharging Pair of Wells in an Aquifer Having Areal Parallel Flow. Internat. Union Geodesy and Geophysics, Internat. Assoc. Sci. Hydrology, General Assembly at Helsinki, 1960, pub. no. 52, Commission of Subterranean Waters, p. 524-536, 1961.
3. Skibitzke, H. E. The Use of Radioactive Tracers in Hydrologic Field Studies of Ground-Water Motion. Internat. Union Geodesy and Geophysics. Internat. Assoc. Sci. Hydrology, General Assembly at Toronto, 1957, v.2: p. 243-252, 1958.
4. Theis, C. V. The Effect of a Well on the Flow of a Nearby Stream. Trans. Amer. Geophysical Union, part 3: p. 734-738, Aug. 1941.
5. Walton, G. ABS Contamination. Jour. Amer. Water Works Assoc. v. 52, no. 11: p. 1354-1362. 1960.
6. Wyllie, M. R. J., and Gardner, G. H. F. The Generalized Kozeny-Carman Equation: Its Application to Problems of Multiphase Flow in Porous Media, Part 2. World Oil, Production Sect., v. 146: p. 210-228. 1958.

GROUND WATER RECHARGE--NATURAL AND ARTIFICIAL*

By R. T. Sniegocki, U.S. Geological Survey

In the science of ground water hydrology, two general methods of recharge--the process by which water enters a ground water reservoir--are recognized. The first is natural recharge, a phenomenon that occurs as a natural process uninfluenced by man. The second is artificial recharge, which is defined as any procedure that artificially increases the amount of water entering a ground water reservoir.

In general terms, contamination of ground water reservoirs is the result of natural or artificial recharge. Consequently, a knowledge of the processes involved in recharge is necessary if a solution to the problem of ground water contamination is to be reached.

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NATURAL RECHARGE

Precipitation is the ultimate source of water for replenishment of ground water supplies. When precipitation strikes the ground, part of it sinks into the soil - a process termed infiltration. Downward movement of water in soil takes place by two methods. The first is a gradual wetting of small particles as the moisture is drawn by capillary forces from wet to dry grains. The second is saturated flow through the openings between particles under the influence of gravity. The addition of precipitation to a ground water reservoir by these processes is considered to be natural recharge. In addition to this, water from streams or lakes may enter the ground water reservoir. This also is natural recharge--the source of the recharged water is precipitation and water moves into the ground water reservoir under the influence of gravity.

Where water table conditions exist, i.e., where the surface of the saturated zone is not confined by a relatively impermeable layer, recharge from precipitation is direct and the time of travel from the land surface to the ground water body is relatively short, usually a matter of hours or days. Contamination from surface wastes usually can be attributed to conditions where such recharge is possible.

Where artesian conditions exist, i.e., where the surface of the saturated zone is confined by a relatively impermeable layer, recharge is indirect and the time of travel may be a matter of years or centuries. Generally recharge to artesian aquifers occurs in the outcrop areas where water table conditions exist, but in some of the deeper and more extensive aquifers, some of which do not crop out at the surface, recharge must occur through the relatively impermeable layers. Artesian aquifers generally are much less likely to be contaminated than water table aquifers.

ARTIFICIAL RECHARGE

Artificial recharge may be classified in a number of ways, such as planned and unplanned, or direct and indirect. For the purposes of this paper the classifications direct and indirect will be used. Direct artificial recharge may be accomplished by:

1. Water spreading.
    a. Flooding areas.
    b. Admitting water into shallow basins, ditches, or furrows.
    c. Extending the time during which water is recharged naturally from a stream or lake.
    d. Applying excess irrigation water.
2. Recharge through pits or other excavations of moderate depth.
3. Recharge through wells and shafts.

Indirect artificial recharge may be accomplished by:

1. Inducing movement of water from a lake or stream into the ground by lowering the ground water level near the source of surface water.
2. Inducing movement of additional water into the ground water reservoir by lowering the water level in areas of rejected natural recharge (1).
3. Inducing movement of water from one aquifer into another aquifer.

Direct Methods

Water spreading is the release of water on the ground surface to increase the quantity of water available for infiltration into a ground water reservoir. Recharge takes place as it does under natural conditions. Field studies have shown that many factors control the rate at which water will enter the soil - the most important quantitative aspects are the character of the soil, area of recharge, and length of time water is in contact with the soil.

With the exception of extending the time of natural recharge from a lake or stream, the listed methods of water spreading are variations of the manner in which water is applied to the soil. Obviously, water-spreading methods of recharge can be used only where the surface materials are permeable.

Weirs, dams, levees, and other similar structures are used to retain water in streams and lakes, thus extending the period of natural recharge. In this specialized method of water spreading, the streambed or lakebed must be permeable.

In areas where spreading methods are not effective because subsurface strata restrict the downward passage of water, artificial recharge can be accomplished only through pits, shafts, or wells. These types of recharge facilities cost more to construct and generally recharge smaller volumes of water than water-spreading areas. Their advantage lies in compactness of recharge facilities and adaptability to the geological environment. Recharge through wells also may be used advantageously for purposes other than increasing the ground water supply. At Manhattan Beach, Calif., water is injected into a line of recharge wells to create a fresh water barrier that prevents further contamination by intrusion of sea water into a confined aquifer. In several parts of Florida, wells that penetrate limestone are used for disposal of storm drainage. Industrial applications of artificial recharge for purposes other than increasing the ground water supply include industrial waste disposal and water flooding through wells for secondary oil recovery.

Rates of artificial recharge by direct methods vary widely. Much of the current research on the subject is directed toward determining what factors control rates and how these factors operate. Factors such as time, soil, temperature, sunlight, bacteria, vegetation, chemicals, subsurface geology, head of water, water quality, and permeability have been investigated. Because of the diversity of factors that affect recharge by direct methods, caution is necessary in designing recharge systems and designs must be based on the geologic and hydrologic conditions in a given locality rather than on specific features observed in other localities.

Indirect Methods

Artificial recharge can be accomplished by withdrawing ground water at a location adjacent to a lake, stream, or an area of rejected natural recharge so that lowering of the ground water level will induce water to enter the ground from the surface source.

Where supplied by a perennial stream, induced recharge assures a continuing water supply even though overdraft conditions may exist in nearby areas supplied only by natural recharge. The method is effective in certain geological environments and is accomplished more easily than most direct methods of artificial recharge. The factors that most affect operation are distance of the well from the surface source, transmissibility of the aquifer, and the degree of hydraulic connection existing between the surface source and aquifer. Where artesian aquifers underlie surface water bodies, the degree of hydraulic connection depends upon the permeability of the confining bed between the aquifer and the surface water body. The degree of connection between surface water sources and an artesian aquifer generally is poor, and recharge of significant magnitude cannot be induced.

WATER QUALITY AND CONTAMINATION

The subject of water quality and contamination deserves critical study in all phases of man's development and use of water, particularly when artificial recharge is considered. Water quality, chemical and bacterial, not only determines the suitability of recharged water for future use but also may determine the feasibility of recharging artificially. Todd(2) lists more than 30 studies on artificial recharge of ground water, in which the principal objectives of the investigations were to determine (1) the effects of microorganism activity on infiltration rates, (2) distance of travel of bacterial or chemical contamination, and (3) changes in temperature and chemical quality of water in the aquifer.

Chemical contamination may move farther through an aquifer than bacterial contamination and generally is more difficult and expensive to remove from the water when it is reclaimed. For example, studies of water spreading made in the Los Angeles area by Hedger(3) have shown that infiltrated water was bacterially safe within 7 feet of the ground surface. Studies of recharge in seepage ponds near Hamburg, Germany, by Holthusen(4) have shown that chemical tracers were detected 280 feet away from the point of recharge and, although river water was used as the recharge source, the bacteria count of reclaimed water never exceeded 2 bacteria per cubic centimeter.

An extensive investigation by the California State Water Pollution Control Board (5) of pollution travel where ground water is recharged by use of wells, showed that contamination was greatest in the direction of ground water movement and that the maximum distance of travel of bacteria was about 100 feet; chemical changes, on the other hand, were noted more than 225 feet from the point of injection.

In areas where induced recharge occurs, water in the aquifer will be modified by mixing with the recharged water. Examples of this may be found in the lower Arkansas River valley in Arkansas near the southern end of the Grand Prairie region. The piezometric surface has been lowered enough to reverse the natural gradient, and water from the Arkansas River moves into the aquifer. The chemical composition of the mixture of induced water and ground water is intermediate between the two native waters.

Rorabaugh(6) reports that, for ground water supplies near the Ohio River, "Apparently, objectionable odors and tastes, which have been a major problem in treating of surface water, are removed or diluted by an induced percolation system. Data are lacking to prove this point definitely."

Studies of recharge of industrial wastes in Nassau County, N. Y., (7, 8) have demonstrated that contamination caused by artificial recharge can be serious. Chromium was detected in the ground water body in 1942, and continued study of the pollution revealed the presence of cadmium. These reports indicate that if additional contaminants are not added to the aquifer the quality of the ground water in the contaminated area should improve in time because of dilution.

A study of literature on artificial recharge points out that recharge rates are a function of many variables and are influenced strongly by factors such as absorption, saturated and unsaturated flow, mechanical filtration, biochemical changes, and other processes not fully understood. Each of these has its effect on recharge and consequently may change greatly the possibility of contamination in different localities where artificial recharge may be attempted.

REFERENCES

1. Meinzer, O. E., 1946, General principles of artificial ground-water recharge: Econ. Geology, v. 49, no. 3, p. 191-201, May.

2. Todd, D. K., 1959, Annotated bibliography on artificial recharge of ground water through 1954: U.S. Geol. Survey Water-Supply Paper 1477, 115 p.

3. Hedger, H. E., 1950, Los Angeles considers reclaiming sewage water to recharge underground basins: Civil Eng., v. 20, no. 5, p. 323-324.

4. Holthusen, W., 1933a, Fünf Jahre Grundwasseranreicherung in Curslack (Five years of supplementing ground water at Curslack): Gas- u. Wasserfach, v. 76, no. 27, p. 525-528, no. 28, p. 545-552.

5. California State Water Pollution Control Board, Sacramento, Calif., 1954, Report on the investigation of travel of pollution: Sanitary Engineering Research Laboratory, Pub. 11, 218 p.

6. Rorabaugh, M. I., 1951, Stream-bed percolation in development of water supplies: Trans. Internat. Assoc. Sci. Hydrology, Gen. Assembly at Brussels, p.165-174.

7. Davids, Herbert W., 1951, Underground water contamination by chromium wastes: Water and Sewage Works, v. 98, no. 12, p.528-529.

8. Lieber, Maxim, 1954, Contamination of ground water by cadmium: Am. Water Works Assoc. Jour., v. 46, no. 6, p. 541-547.

SOME ASPECTS OF CHEMICAL EQUILIBRIUM IN GROUND WATER

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FACTORS THAT AFFECT GROUND WATER COMPOSITION

Liquid water moving in the hydrologic cycle is in contact with various rock minerals, organic and inorganic constituents of soils, and gases present in the atmosphere or produced by biologic or other processes at or below the land surface. As a result of these contacts, solution or chemical reaction followed by solution takes place and the water accumulates numerous dissolved impurities. The actions of man also contribute dissolved impurities.

The amount and kinds of dissolved material that a ground water contains reflect in a general way a good many features of the prior environment of the water. The influence of individual factors such as the geologic character of that environment, biologic activity in soil or impounded water, or the pollutants that might be present may sometimes be strongly evident. Unless supplementary information on geology, hydrology, and other factors has also been obtained, the chemical character of the water often cannot be fully explained.

The chemical composition of ground water is certainly strongly influenced by things that happened to the water before it entered the ground water reservoir. Once it has arrived in an aquifer, however, the water is subject to a fairly stable set of conditions. Ground water moves slowly and is therefore in contact with a large surface area of solid-phase rock minerals for considerable periods of time. Temperature or pressure changes may occur in ground water reservoirs, and organic matter and bacterial activity may influence ground water composition. On the whole, however, the conditions within a ground water reservoir favor the establishment of chemical equilibria in the reversible chemical reactions that may occur among the solutes contained in the water and the solids in the aquifer.

CHEMICAL EQUILIBRIA IN GROUND WATER

The principles of dilute solution chemistry have been extensively described over the past half century or so. Chemical equilibria that may exist in ground water systems can therefore be examined by the use of these established principles. Effects on natural equilibrium of injection of recharge water through wells, effects of pollutants, and effects of pumping such as the accumulation of clogging deposits on and around well screens, all can be better understood if the chemical factors involved are considered.

Types of chemical reactions that are reversible and rapid enough to make it likely they will reach equilibrium in most ground water systems include:

1. Adsorption or desorption of cations and anions held on surfaces of solids.

2. Solution and deposition of carbonate minerals.
3. Oxidation or reduction, and hydrolysis reactions of certain metals, such as iron.

Sorption Reactions

The capacity to adsorb cations from solution is strongly developed particularly in the clay minerals, but many other common rock minerals have at least a small capacity for adsorption. Productive aquifers generally contain little clay, although enough may be present as a thin coating over sand grains and larger rock particles to give a considerable adsorptive capacity. The strength of the forces holding the adsorbed ions is greater for divalent ions than for monovalent ones. Also the ions having small radii are held more tightly than those with large radii. The amounts and kinds of exchangeable ions held by solids in an aquifer are in equilibrium with the supply of solutes in the water that is present. Adsorbed ions may be removed and replaced by others, if the nature of solutes changes.

A commonly observed effect is the natural softening of ground water that occurs in some aquifers. This effect is brought about by replacement of exchangeable sodium from the solid material with calcium and magnesium from the water. As the exchangeable sodium is depleted by circulation of water through the aquifer, the capacity of parts of the aquifer to soften the water decreases.

Research on the ion-exchange properties of natural materials is currently being carried on by the Geological Survey and by other agencies, but much remains to be learned about the relationships of the exchange reactions to ground water quality.

Carbonate Equilibria

Carbonate minerals are very common in granular aquifers, as individual grains or as coatings on the grains. Massive carbonate rocks, such as limestone, may themselves act as aquifers. Water moving along fissures in such rocks enlarges the channels by solution, and ultimately the rock may contain large openings.

A large amount of work has been done on the chemical behavior of calcium carbonate. Some of the conclusions indicated by the literature are:

1. Reactions by which calcite is dissolved or precipitated are rapid enough to require consideration and control in distribution of water supplies (1).
2. Comparison of the actual pH of a solution with the calculated pH of that solution in chemical equilibrium with respect to calcite can provide a useful index of the future behavior of the solution when brought into contact with solid-phase calcite (10).
3. Water in the pores of limestone is normally saturated with respect to calcite (12).

Probably this last conclusion can be extended to any rock in which calcite is present in important quantities.

In the simplest terms, with a temperature of 25° C and a pressure of 1 atmosphere assumed, the equilibrium for calcite in water is:

$$CaCO_3\ c. + H^+ \rightleftharpoons HCO_3^- + Ca^{+2} \quad *$$

This system does not contain a gas phase and is likely to be the usual condition below the water table. The equilibrium constant K_{eq} can be computed from the relation

$$\Delta F^0 = -RT \ln K_{eq}$$

where, ΔF^0 is the net change in standard free energy when the reaction goes from left to right, R is the gas constant, T is the temperature in degrees Kelvin, and $\ln K_{eq}$ is the Napierian (or natural) logarithm of the equilibrium constant. Standard free energy values for calcite and the ions involved are available in texts such as that of Latimer

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[*] The symbol "c." represents the crystalline solid state of the substance. Positive and negative superscripts represent ionic forms.

(11). At 25° C, the equilibrium pH for a water may be computed from the mass-action law, with the activity of calcite assured to be unity.

$$pH\ eq = -\log \frac{\left[Ca^{+2}\right]\left[HCO_3^-\right]}{K_{eq}}$$

The quantities in square brackets are thermodynamic concentrations, or activities of dissolved ions, and are computed from the concentrations reported in chemical analyses by means of the Debye-Hückel limiting law. Procedures for making these computations are given by Klotz (9), and an adaptation of these procedures with graphical aids developed by the writer (5) is particularly adapted for use with data from standard water analyses.

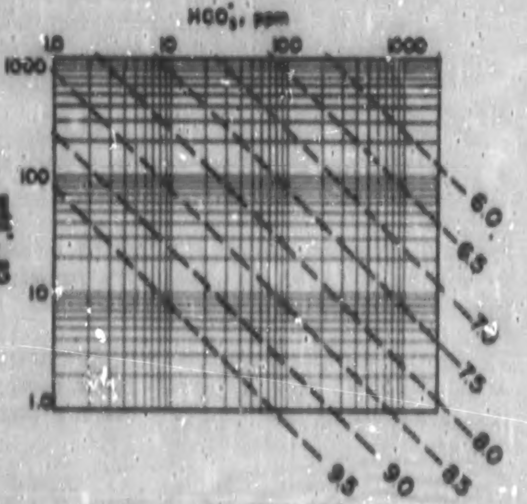

FIGURE 1. EQUILIBRIUM pH IN RELATION TO CALCIUM AND BICARBONATE ACTIVITIES IN SOLUTIONS IN CONTACT WITH CALCITE – TOTAL PRESSURE 1 ATMOSPHERE AT 25°C

Figure 1 is a graph showing the equilibrium pH computed from the above equation for a solution in contact with calcite in relation to dissolved calcium and bicarbonate activities. The differences between the concentrations of calcium and bicarbonate reported in analyses and the effective concentrations, or activities, may be substantial. In general, the activity of calcium in a solution whose total dissolved solids concentration is near 400 ppm is about 70 percent of the measured concentration of calcium. The bicarbonate activity in such a solution would be about 90 percent of the measured concentration. In a water whose total dissolved solids is about 4000 ppm, the calcium activity is about 40 percent of the measured calcium concentration and bicarbonate activity is about 75 percent of the measured bicarbonate concentration. For waters that contain more than 5000 ppm dissolved solids, the relationships of measured concentrations to activities are less well defined.

Figure 1 represents conditions at 25° C. The solubility of calcite decreases somewhat at increased temperature (13), and temperature deviations from 25° C also affect the activity corrections and the pH measurements. Temperature corrections probably are not needed in the practical application of the diagram to waters that are within 15° or so of 25° C. It should be remembered, however, that the results obtained in this way are approximations and that rigorous application of the principles requires the use of more exacting methods. Because the pH of solutions may change in stored samples, measurements of this property should be made in the field when water samples are collected.

Chemistry of Iron

The chemical behavior of a considerable number of metals, which may be present naturally in very small quantities in ground water or which may be added in waste disposal, is similar in certain respects to the behavior of iron. Theoretical data for iron are readily available.

Laboratory and theoretical studies (3, 4, 5, 6), as well as practical experience with the behavior of natural water, have shown that equilibrium with respect to some of the commonly found sedimentary iron minerals is to be expected in ground water.

The kinds of equilibria that are most important in iron chemistry include:

1. hydrolysis, with or without oxidation or reduction, for example

$$Fe^{+3} + H_2O \rightleftharpoons FeOH^{+2} + H^+$$

2. solution and precipitation reactions involving anions other than OH^-, such as

$$FeCO_3\ c. + H^+ \rightleftharpoons Fe^{+2} + HCO_3^-$$

3. redox equilibria, such as

$$Fe(OH)_3\ c + 3H^+ + e \rightleftharpoons Fe^{+2} + 3H_2O$$

The symbol "e" represents the unit negative electrical charge gained by each ion of iron reduced. Conditions at equilibrium in a system involving water, dissolved ions, and iron-bearing minerals such as ferric hydroxide (or hydrated ferric oxide), siderite, or the sulfide minerals such as pyrite can be evaluated by means of equilibrium constants along with relationships involving the redox potential.

The redox potential of a solution, represented by the symbol Eh, is a measure of the relative intensity of oxidizing or reducing conditions in a system. It is expressed in volts and at equilibrium is related to the proportion of oxidized and reduced forms present. The relationships can be expressed by standard equations of chemical thermodynamics.

The standard potential, E^0, of a redox system is the potential under standard conditions, when unit activities of participating substances are present. It is related to standard free energy change in a reaction by the equation

$$\Delta F^0 = - n f E^0$$

where n is the number of unit negative charges shown in the redox reaction and f is the Faraday constant in units that give a potential in volts. The redox potential in systems not under standard conditions is given by the Nernst equation

$$Eh = E^0 + \frac{RT}{nf} \ln \frac{[\text{oxidized species}]}{[\text{reduced species}]}$$

The algebraic signs of Eh and E^0 are arbitrarily assigned. In geochemical literature (2), increasingly oxidizing conditions are represented by increasingly positive potential values.

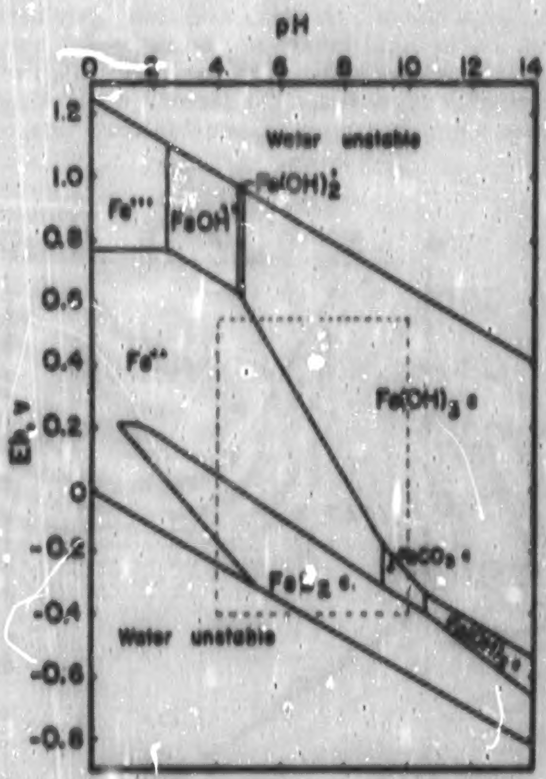

FIGURE 2. STABILITY FIELDS FOR AQUEOUS SYSTEM IN WHICH MAXIMUM DISSOLVED ACTIVITIES ARE: IRON AS Fe, 0.01 ppm; CARBONATE SPECIES AS HCO_3^-, 100 ppm; SULFUR SPECIES AS SO_4^{--}, 10 ppm — TOTAL PRESSURE 1 ATMOSPHERE AT 25°C

Figure 2 is a stability-field or Eh-pH diagram of a hypothetical system containing dissolved iron and a constant activity of ions derived from dissolved carbon dioxide, such as bicarbonate, and of ions derived from sulfur, such as sulfate. The boundaries were computed by equilibrium calculations and show the conditions of Eh and pH at which the common ionic species of iron would be stable. Stability fields for solids show those areas where activity of iron in solution would be less than 0.01 ppm. The nature of the solid formed depends on the form and amount of anions present, as well as on Eh and pH.

The field of stability shown for pyrite entails oxidation and reduction of sulfur, and because these reactions are slow, they may not be at equilibrium in natural water systems. Otherwise, however, the diagram probably represents the factors controlling iron solubility, with reasonable accuracy.

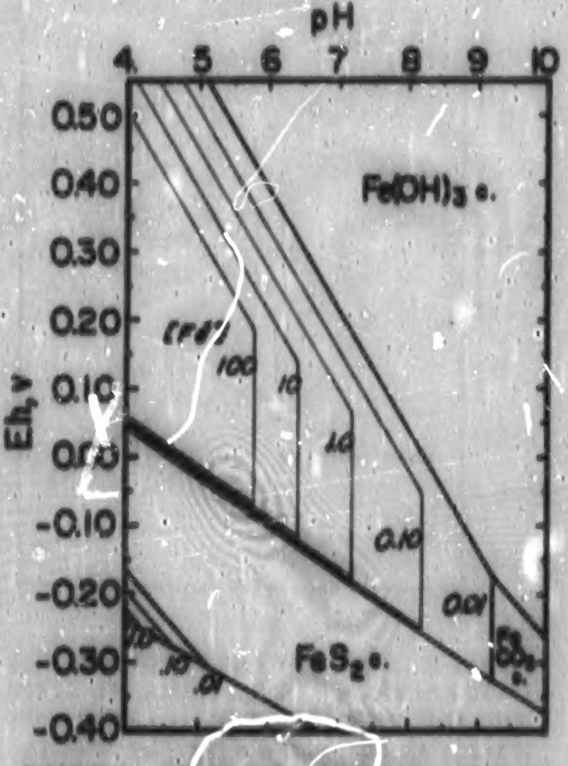

FIGURE 3. DISSOLVED IRON IN RELATION TO pH AND Eh — CARBONATE SPECIES AS HCO_3^-, 100 ppm; SULFUR SPECIES AS SO_4^{--}, 10 ppm

Figure 3 is an enlargement of the area of Figure 3 between pH 4 and 10 and between Eh 0.55 and - 0.40 volts. This covers the usual range of ground water systems. On the diagram are shown the corresponding positions of the solid-phase boundaries for the indicated iron activities from 0.01 to 100 ppm. In effect, these lines represent iron solubility contours for the system in consideration and can be used to explain and predict the behavior of iron dissolved in ground water.

In that part of the field where iron solubility lines are parallel to the $Fe(OH)_3$ c. boundary, the system would be in equilibrium with this solid and dissolved iron is a function of Eh and pH. Where the lines are vertical, the dissolved iron would be in equilibrium with siderite (ferrous carbonate) and dissolved iron is a function of pH and total available dissolved carbonate species. If pyrite is present, oxidation of the sulfur to SO_4^{-2} may occur, releasing ferrous iron in the process, although the equilibrium may not be strictly applicable here. At a very low pH and Eh the pyrite may be reduced to give H_2S and ferrous iron.

Measurement of Eh in natural waters is subject to difficulties. Generally, the amounts of the dissolved ions present, which set the Eh of a ground water system, are small, and even a short contact of the solution with air introduces enough oxygen so that the measurement is indicative of the effect of dissolved oxygen and not that of the system that controlled the Eh while underground and out of contact with air. Care in sampling or placement of electrodes is therefore necessary, and in some wells no measurement can be made before aeration of the pumped water has taken place. The measuring equipment may sometimes be affected by stray electrical currents and may require electrical shielding. In some instances, e.g., where measuring electrodes can be inserted in the discharge pipe of a flowing well, a measurement of Eh that is meaningful may be obtained but there is reason to doubt the practicability of obtaining extensive Eh data by direct measurement in the field.

If complicating factors such as the formation of chemical complexes are ignored, it is evident from Figure 3 that any water containing 1.0 ppm or more of iron is going to retain that amount of iron in solution only at low pH, intermediate Eh, or both. Generally pH can be measured more easily than Eh, but the Eh of ground water can be estimated from Figure 3 on the basis of observed iron content and pH, provided one knows which solid form is involved in the equilibrium.

Over the entire area of Figure 3, iron in solution is controlled by four somewhat interrelated variables, Eh, pH, HCO_3^-, and SO_4^{-2}. If a water contains 1 ppm of iron at Ph 7 and the Eh is +0.10 volt, the dominant solid phase form of iron present is ferric hydroxide, when bicarbonate activity does not exceed 100 ppm and sulfate activity does not exceed 10 ppm. Siderite could not be the dominant solid phase at this level of bicarbonate activity at pH 7 unless the Eh were lower. If the dominant solid is pyrite, the equilibrium Eh would be about -0.16 volt, but this condition is less likely than the other possibilities.

If the activity of bicarbonate species is decreased by a factor of 10, the vertical iron concentration lines are shifted to the right by 1 pH unit and the stability field for siderite at 0.01 ppm activity of iron disappears. At low levels of bicarbonate, therefore, the influence of carbonate equilibria on iron content is not very important at pH 7. If the bicarbonate activity were increased to 1000 ppm, the presence of 1 ppm Fe^{++} at pH 7 would not be possible at equilibrium. The pH would have to be lower (< 6.2) to permit 1 ppm of iron to be retained in solution.

Changes in sulfur activity have only a minor effect on the position of the pyrite boundary. Changes of a factor of 10 in total sulfur species move the boundary of the pyrite field less than 0.01 volt.

Huber (7) has discussed some aspects of iron equilibria in systems containing carbonate and sulfur.

Factors That Alter Equilibria

The effects of adding solutes from external sources to a ground water system that is at chemical equilibrium can be predicted. Disposal of wastes or injection of artificial recharge through wells are instances in which considerable amounts of solutes foreign to the equilibrium may be added to ground waters.

Some dissolved metals are very strongly adsorbed by solids with cation exchange capacity. Such metals may disappear from solution when introduced into ground water, displacing previously adsorbed cations as the metal ions take up exchange positions on the solid. The adsorbed metals however can be displaced themselves at a later time. The processes of adsorption and desorption in aquifers require considerably more research before they can be fully evaluated.

Where equilibrium has been established with respect to calcite, changes in pH or calcium or bicarbonate activity will bring about renewed chemical reaction. For example, lowering the pH will cause more calcium carbonate to dissolve, whereas raising the pH would cause calcite to precipitate. In most ground water the pH is controlled in part by effects of dissolved carbon dioxide. The amounts of the gas dissolved are affected by temperature and pressure. A reduction in head, such as may be induced at a pumping well, decreases the availability of dissolved carbon dioxide and may raise the pH of the water enough to bring about calcium carbonate precipitation. Although the effects brought about by disturbing chemical equilibrium have not yet been closely studied in ground water hydrology, they may often be important and should be more thoroughly investigated.

If a ground water is iron bearing or if other metals that may precipitate on oxidation are present, the system at equilibrium will be more precariously balanced than the one involving calcite. Raising the redox potential by introducing air or solutions of chlorine may cause the metals to precipitate. A similar effect also can be brought about by increases in pH, whether or not redox potentials are changed. Polluted water may also contain materials that lower the redox potential of a ground water system. A decrease in redox potential may bring increased amounts of previously precipitated metals into solution in the aquifer.

Precipitation within a ground water aquifer tends to plug the channels through which water may move. Solution of solid material from the aquifer adds to the dissolved-solids content of ground water, which may or may not be excessively undesirable, depending on the nature and amount of material that is involved. Both effects however need consideration in the development and use of ground water.

REFERENCES

1. Fair, G.M., and Geyer, J.C. Water Supply and Waste Disposal. John Wiley and Sons, New York. 1954. 973 p.
2. Garrels, R. M. Mineral Equilibria at Low Temperature and Pressure. Harper and Bro., Boston. 1960. 254 p.
3. Hem, J.D. Chemistry of Iron in Natural Water -- Restraints on Ferrous Iron Content Imposed by Bicarbonate, Redox Potential and pH. U.S. Geol. Survey Water-Supply Paper 1459 B. 1960.
4. Hem, J.D. Chemistry of Iron in Natural Water -- Some Chemical Relationships Among Sulfur Species and Dissolved Ferrous Iron. U. S. Geol. Survey Water-Supply Paper 1459 C. 1960.
5. Hem, J.D. Calculation and Use of Iron Activities in Natural Water Chemistry. U.S. Geol. Survey Water-Supply Paper 1535 C. 1961.
6. Hem, J.D., and Cropper, W.H. Chemistry of Iron in Natural Water -- A Survey of Ferrous-Ferric Chemical Equilibria and Redox Potentials. U.S. Geol. Survey Water - Supply Paper 1459 A. 1959.
7. Huber, N. K. The Environmental Control of Sedimentary Iron Minerals. Economic Geology, 53:123-140. 1958.
8. Huber, N. K., and Garrels, R.M. Relation of pH and Oxidation Potential to Sedimentary Iron Mineral Formation. Economic Geology, 48:337. 1953.
9. Klotz, I.M. Chemical Thermodynamics. Prentice-Hall, New York. 1950. 329-332.
10. Langelier, W. F. The Analytical Control of Anti-Corrosion Water Treatment. Journal of the American Water Works Association, 28:1500. 1936.
11. Latimer, W. M. Oxidation Potentials, 2d ed. Prentice - Hall, New York. 1952. 392 p.
12. Weyl, P.K. The Solution Kinetics of Calcite. Journal of Geology, 66:163-176. 1958.
13. Weyl, P.K. The Change in Solubility of Calcium Carbonate with Temperature and Carbon Dioxide Content. Geochimica et Cosmochimica Acta, 17: 214-225. 1959.

ASPECTS OF GROUND WATER INVESTIGATIONS AS RELATED TO CONTAMINATION

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The Ground Water Branch of the U.S. Geological Survey is charged with the responsibility of investigating the quantity, distribution, availability, and utilization of the underground water supplies of the country. In conjunction with the Surface Water and Quality of Water Branches, determination also is made of the relation of ground water resources to surface water resources and the variations, causes, and effects of the quality of the ground water. Contamination, therefore, is a factor that must be considered in any ground water investigation.

Ground water investigations are designed to study the ground water resources of a specified area and to determine cause and effect relationships for such phenomena as deterioration in quality. The boundaries of the areas may be determined arbitrarily to coincide with county or State boundaries, or they may be based on hydrologic criteria and enclose entire drainage basins or geohydrologic units. Most areal studies are undertaken in cooperation with state or local agencies, some are done at the request of and are supported by other Federal agencies. In addition to areal investigations in the field of ground water, the Survey does basic research, studies principles and techniques of hydrology, studies occurrence of ground water by types of terrane, and maintains a system for the collection of basic records.

Contamination of ground water is not always suspected. In many instances its existence becomes known as the result of areal investigations whose prime purpose was an evaluation of the resource. Where contamination is known or suspected, however, a special areal investigation may be made with the objective of determining the geologic factors required for a full understanding of the problem.

Previously, Mr. R. H. Brown discussed the hydrologic factors and Mr. P. E. LaMoreaux the geologic controls that govern contamination of ground water. Areal reports describe the geology and hydrology of the area under investigation so that the hazards of existing or potential contamination may be understood in relation to the entire geohydrologic environment. Some knowledge of the areal geohydrology is prerequisite to the correction or prevention of contamination.

The discussion of investigations in this paper will be confined to studies of areas. The detailed procedures involved in areal ground water studies differ, depending on such factors as geographic location, geology, climate, kinds of water problems, and size of area, but the general procedures are similar, irrespective of local details. Any ground water investigation may be separated into thre steps--planning, execution, and reporting. Although this paper is concerned primarily with execution, some discussion of planning and reporting is necessary. The importance of financing, acquiring and training personnel, and details of preparing the report is recognized, but discussion of these is beyond the scope of this paper.

PLANNING

The scope of an investigation may be classified, on the basis of intensity of effort, as reconnaissance, detailed reconnaissance, or comprehensive. These terms are used merely to indicate in a general way the variation in the scope of investigations. Generally, a reconnaissance investigation is made of an area where little or nothing is known of the ground water resources. The objectives often are to determine the general occurrence and quality of water, both areally and within the geologic column, the importance and types of use of ground water in the area, and the kinds and locations of existing and potential problems, including contamination. A rapid reconnaissance may be necessary to determine the need for a more thorough or particular type of investigation. The area covered by a reconnaissance investigation may contain only a few square miles, but often includes several hundreds or thousands of square miles.

The detailed reconnaissance investigation usually covers a smaller area than the reconnaissance. The objectives may be much more specific and might include, in addition to those of the reconnaissance, a quantitative study of a part of the area or of one or more parts of the geologic section, or a study of the occurrence of water of a certain quality. Such a study is made in an area where there are known local or potential problems and where basic information is required for their solution.

The comprehensive investigation commonly covers an area not larger than a few hundred square miles. The objective of the comprehensive investigation is to describe the ground water resources of the area, quantitatively and qualitatively. The investigation includes sufficient analysis of recognizable problems that the necessary data can be collected and presented in usuable form to those who are responsible for the actual solution of the problems. Ideally, the relation of ground water to surface water and the quality of ground water, including changes owing to development, are determined and described so that the entire water resources of the area may be developed fully and efficiently. Rarely is it practical to meet all the above objectives. The investigation, therefore, generally is tailored to meet the objectives within the limits prescribed by time and funds.

The length of time and amount of effort required for an areal investigation depend upon the size of the area, the complexity of the geologic and hydrologic environment, the amount of data readily available, and the scope of the investigation. Typical studies may last only a few months or as long as 10 years, and the effort required may range from a few man-months to tens of man-years.

Eventually the entire country will be covered by reconnaissance or comprehensive investigations. The increasing use of water makes it mandatory that information necessary for full and orderly development of all sources of water be obtained. On the other hand, the immensity of the task precludes its completion in the foreseeable future. As the country becomes more fully developed and as the demand for water expands and water problems such as contamination come to the forefront, areas now adequately covered by reconnaissance investigations may need more comprehensive re-evaluation. Water is a dynamic resource, and for no area can it be said that knowledge of its occurrence is adequate for all needs. Obviously then, those areas that are the most important - where problems exist or soon will exist and where water is in great demand - must be investigated first.

Ground water problems may be classified as problems of quantity, quality, distribution, development, and conflict of interest; contamination may be the principal or a contributing factor in either classification. Rarely can the problems in an area be relegated to a single classification, but the terms are useful, nonetheless, for indicating the type of information and investigation that will be needed for full utilization of the resource.

Conditions under which each kind of problem may occur include the following. These examples are hypothetical, but they summarize the conditions in many areas where studies have been or are being made. An industrial area may be situated where only a certain amount of water can be withdrawn from the underlying aquifers (water-bearing units). As the demand for water exceeds this limit, there is a problem of quantity. Water from an aquifer may be or may become too saline to use for irrigating crops or for an industrial process and thus present a quality problem. If undeveloped water is available from an aquifer present in only some parts of an area, there is the problem of distribution. If an aquifer will yield large quantities of water only with a continual decline of water levels, there is the problem of development. Ground water needed for irrigation during periods of low rainfall may be the source of low flow for a trout stream; thus, there is a conflict of interest between agriculture and recreation.

Conducting The Investigation

Any investigation consists of developing the background and objectives of the study, collecting data, compiling the data, interpreting the data, making conclusions, and presenting the results to those who need them. Much of the sort of information that makes up the background already has been discussed. Not all the details of a procedure for a specific ground water investigation necessarily apply to all investigations.

The objectives of a comprehensive investigation have been said to include a quantitative description of the ground water resources, their quality, and their relation to surface water. The objectives may be stated more specifically: (1) to determine the hydrologic properties and the dimensions of each unit in the geologic section, at least down to the deepest source of water usable for any practical purpose, (2) to determine the source and amount of recharge to each aquifer, (3) to determine the amount and location of discharge from each aquifer, (4) to determine the quality of the water from each aquifer, (5) to determine the effects of withdrawal of water from each aquifer, (6) to determine the effects on surface water of changes in recharge and discharge of ground water, (7) to determine the movement of water, and (8) to determine the effects on ground water of the changes in the regimen of surface water. Within a given area the objectives may be detailed even further, and some of those listed may not apply. Modifications of the initial objectives may become necessary as the investigation progresses and previously unknown factors are recognized.

The collection of data is the first work to be done in the field, but it must be preceded by a thorough search of the literature and other sources of information. For example, much information may be stored in the files of public agencies. A search of the literature commonly will yield considerable geologic information and may give information on the history of well drilling and water development in the area. In addition to scientific reports, newspaper files and historical articles or books may yield significant information. An examination of surface water records may reveal areas and magnitudes of recharge or discharge of ground water.

The hydrologist, following the literature search, will have prepared an outline for the work and a first outline of his final report. These outlines will be similar and, in a sense, will complement each other. For example, as a phase of the work is completed, it becomes an inactive part of the work outline and may be ready for writing into the report. The outlines are based on the background data, the information obtained from the literature, and the objectives of the investigation.

The fieldwork may be divided into phases --geologic mapping, inventorying of wells, logging of wells, observations of water levels, collecting water samples for chemical analysis, collecting data on amount of pumpage and use of water, test drilling, and pumping tests and inflow studies. Some of these phases may be undertaken simultaneously, for example, inventorying of wells, measurement of water levels, and collection of water samples. Some phases may be interdependent; the amount of test drilling needed will depend on number and locations of existing wells and the adequacy of information on them.

Geology is the key to any ground water investigation. It follows, therefore, that geologic mapping, both of the surface and the subsurface, is one of the first field phases of an investigation. In most areas some geologic mapping has been done and serves as a basis for that required in a ground water study. Surface mapping is done in the field and is supplemented by areal photographs and drilling records. Particular attention is given the geohydrologic units and contacts that will most affect the occurrence, movement, and quality of ground water.

With few exceptions subsurface geologic mapping of such phenomena as thickness and configuration of aquifers is lacking. The subsurface is mapped from logs of wells and, in some places, with the aid of geophysical techniques. The logs are collected from well drillers, well owners, public-agency files, and oil and gas exploration companies. If possible, wells for which no logs are available are logged by electrical-resistivity and gamma-ray equipment and correlated with known geology.

While the geology is being mapped, the existing wells and springs in the area are scheduled, i.e., the area is visited and all information is recorded relative to elevation, depth, diameter, location, age, water level, pumping rate and drawdown, use, and formations penetrated. Water samples are collected from wells and springs representative of various aquifers at various locations. These smaples are sent to a laboratory for analysis. If it is known or suspected that a quality problem exists of if the early analyses show that one exists, partial analyses may be made in the field to determine the best locations for more extensive and detailed sampling.

In addition to the water level measurements made at the time wells are inventoried, water levels in selected wells are measured periodically and automatic recorders are installed on some to determine rates and magnitudes of fluctuations. Also, owners of production wells are canvassed to determine the amount and rate of withdrawal of water from the entire area.

Test drilling is necessary where the data from existing wells are so incomplete that interpolation and interpretation cannot fill the gaps. It may be necessary to determine the lateral extent of or change in formations, to obtain samples of rocks and of water otherwise unobtainable, or to provide wells for conducting pumping tests.

Pumping tests are made by use of existing wells or wells drilled for that purpose. These are tests of the aquifers--not merely of the wells. Simply stated, a test consists of observing the effects of changing the discharge rate from an aquifer for a measured length of time. The effect on other aquifers also is observed; if appropriate, samples of water are obtained to determine changes in chemical content during withdrawal. Pumping tests may last for only a few hours, or they may last for several days or even weeks. The data collected during pumping tests are analyzed to determine the hydrologic properties of the aquifers. These properties in turn are used to determine the behavior of the system in response to natural and artificial changes in recharge and discharge. The uses of tests are limited in that they sample only a portion of the system, but in combination with other information they form a basis for interpretation of the hydrology of more extensive areas.

If streams in the area are hydraulically connected to the aquifers, detailed inflow studies are made to determine the amount of recharge or discharge along all sections of the streams in the area. Samples of water from streams are collected and analyzed, if there is any indication that water from the streams is a source of recharge to the aquifers.

Ground water contamination may become evident during any one of the phases of the fieldwork. The geologic mapping may show the presence of sinkholes that permit the entrance of surface wastes to the aquifers. The inventory of wells may reveal that wells in one part of the area had to be abandoned because the "water became unfit to drink." The observation-well program may show anomalous water levels that can be explained only by corrosion of the casings. Collection of water samples often suggests possible contamination, and further sampling confirms it. Logging of wells often brings up direct evidence of contamination in the samples themselves. Although complete details on contamination problems may require considerable investigation in a concentrated area, the problems may be recognized first by the relatively broad investigative techniques described above.

COMPILATION AND ANALYSIS

The compiling of data serves the threefold purpose of assembling similar kinds of data, preparing data for analysis and interpretation, and checking the adequacy or completeness of data. Compilations of the data are begun to some extent during the fieldwork. Well records, water level measurements, and quality-of-water data are tabulated. Maps and charts are used extensively for compilation because they give a picture of the coverage and the degree of correlation of data. The subsurface geology is shown by sections and on maps by lines that show thicknesses of units or elevations of tops of units. Water level, pumpage, and precipitation data are shown on hydrographs, sometimes with other related climatological data. Maps showing contours that represent the piezometric surface are prepared for each aquifer. Such maps, together with pumpage and geologic information, indicate the hydraulic characteristics of the aquifers, areas of recharge and discharge, and the general directions of movement of water. Quality of water data are shown on various types of graphs and on maps on which isopleths indicate lateral changes in concentrations of certain ions.

Just as compilation goes on during the field stages of the investigation, so do analysis and interpretation during the fieldwork and during compilation. The three activities are interdependent. For example, during the well inventory it may be learned that water from a domestic well has become too salty to drink. The source of the salt may be an underlying saline aquifer, salt water disposal pits from a nearby oil field, or a stream that contains highly mineralized water. Additional sampling of surrounding wells may show that the source of the salt water is not the oil-field brines. Detailed geologic mapping may show that conformation of the strata in such that the well could not draw water from the stream. A test hole in the vicinity may show that the shale layer between fresh and saline aquifers is absent and that the saline water is free to move up into the fresh water aquifer when the head in the fresh water aquifer is lowered.

The interpretation of the data is both exciting and tedious. All data must be examined individually and collectively. Some data can be put together somewhat according to rule or formula. More often one interpretation depends on several other interpretations, and only by careful examination and re-examination of the various parts is it possible to arrive at the best possible interpretation. The degree to which the objectives are met depends upon the amount and reliability of the data, the accuracy of necessary assumptions, and the skill and experience of the hydrologist.

Certain objectives of the investigation may not be met because physical evidence to prove a hypothesis or theory may be lacking and unobtainable, for example, a fresh water aquifer may be separated from a saline aquifer by a nearly impermeable bed. It may be suspected that if the hydrostatic head in the fresh water aquifer is reduced a certain amount saline water will gradually move through the separating bed and contaminate the aquifer. Such a process might take years to prove, but the hydrologist must interpret the situation in terms of potential, as well as present, conditions and arrive at a conclusion. Conclusions are based on reliable data, principles of hydrology and geology, and experience.

THE REPORT

It is sometimes said that the report is the most important part of any investigation. It would be better to say that an investigation is not complete without the release of a well-written, timely report. Only through the medium of published reports can the results of investigations be made available in permanent form to all the potential users of the information.

The report may be brief or several hundred pages in length. Much of the information, including the interpretation, may be presented in the form of graphs, tables, or maps.

Ground water reports may be published by many different agencies -- state, federal, local, quasi-public, or private. The Geological Survey has its own series of reports, but many of its reports are published by the cooperating agencies or are contributed to technical journals. "Open-file" release of Survey reports is not an independent means of "publication" but merely an expedient to make needed information available to the public prior to publication and in the shortest possible time.

SUMMARY

An investigation of the ground water resources of an area is undertaken by the Survey, usually in cooperation with a state or another agency, as a part of the long-range program of evaluating the water resources of the country. The need for the investigation is based on the demand for water and on the problems, present or potential, in the area. Many of the problems are the result of or are influenced by contamination. The investigation is carried out by the collection and interpretation of the data necessary to meet the objectives. The objectives are to describe the environment and the principles governing the occurrence of ground water. The report presents the results of the investigation so that those responsible for water development and management may provide their own solutions to problems that involve not only hydrology but also economics. A knowledge of the areal geohydrology is essential for the solution of problems related to contamination of ground water; a knowledge of the problems of contamination is an integral part of any areal investigation.

DISCUSSION 1

Chairman: H. A. Swenson

Discussion was initiated by Mr. John E. Vogt, who asked Mr. R. H. Brown whether a contaminant that reaches the water table spreads on or near the water surface or penetrates downward into the water-saturated stratum and whether chemical and bacteriological contaminants behave in a similar manner. Mr. Brown replied that the properties - density, surface tension, etc. - of both the waste and the ground water would influence the course traveled by the contaminant.

Mr. Vogt then asked that the case of septic tank effluent that has leached downward through the unsaturated soil to the water table be considered. In reply Mr. Brown referred to his discussion of flow through nonuniform aquifers (Brown's paper, Figure 9) and noted that if the densities of the effluent and the ground water were of the same order the contamination probably would move farther than one would predict. Natural aquifers are not uniform in character, and contaminants tend to channel through the more permeable formations and thus move faster and farther than they would in a homogeneous aquifer.

Mr. George B. Maxey of the Illinois State Geological Survey noted that current water use amounts to 300 to 400 billion gallons per day (bgd) and that various agencies forecast that the 1980 requirements will be around 600 bgd, or about half the total runoff from this country. Ground water resources supply approximately one-sixth or one-seventh of the water now used. Mr. Maxey asked Mr. George D. DeBuchananne whether, with the increasing reuse of water, he believes the greater share of the additional 200 to 300 bgd needed by 1980 will be secured from ground water. Mr. Debuchananne expressed the opinion that the use of ground water is going to increase tremendously and that since readily obtainable stream flows are already nearly 95 percent utilized ground water affords the only water resource available for supplying much of the anticipated threefold increase in the amount of water that will be required 30 years from now.

Mr. DeBuchananne also commented on Mr. Brown's illustration (Figure 9) of the mixing of waste streams from two injection wells. He noted that one or two observation wells may be completely insufficient to monitor waste travel underground. The movement of ground water and of waste streams injected into ground water is dependent on the geology of the region and the heterogeneity of the underground strata.

Noting the extensive use in New England of seismic surveys in ground water investigations, Mr. Ralph M. Soule of the Massachusetts Department of Public Health queried Mr. William J. Drescher about the use of such surveys in other parts of the country. Agreeing that seismic surveys are a very important means of data collection and analysis, Mr. Drescher observed that he had included them under the term geophysical. Also in this category are electrical resistivity tests on the surface and certain down-the-hole tests.

If the rainfall that replenishes ground water supply is exceeded by usage, inquired Dr. Joseph Vogel of Mahopac, New York, will it be necessary to reclaim waste water or seek our water supplies from the oceans? Mr. Drescher, noting that water usage data include reused water, called on Mr. John E. Richards of the Ohio Department of Health to comment on the reuse of water in some Ohio streams. Mr. Richards, in turn, observed that at times of low flow Mahoning River water is used something like 14 times. This prompted the observation that it is impossible at present to compare directly precipitation and water use data.

Two questions on adsorption and ion-exchange phenomena were asked by Barry D. Andres of C. W. Laumen and Company, Inc., Bethpage, New York. Noting that Mr. John D. Hem had mentioned cationic exchange, Mr. Andres asked whether there is any information on anionic exchange and whether there is a difference between inorganic exchange. In reply Mr. Hem noted that he had spoken of cation exchange primarily because most of the natural minerals, particularly the clays, have negative surficial charges. This makes them much more readily amenable to cation adsorption. There is, however, some adsorption of anions.

Mr. Hem further observed that it is known, as work at the Denver Federal Center has indicated, that under certain conditions some of the oxides, such as ferric oxide, have capacity to adsorb anions. It is his belief that things like arsenic and phosphorus, which are found in many iron ores, are there because at the time the ores were deposited the pH conditions were such that the oxide particles had a positive charge and could adsorb these anionic materials on their surfaces. He observed that the adsorption of organic material by inorganic particles does occur. This is a type of adsorption that differs a little, he thinks, from the strongly bound cation-exchange reaction that is usually thought of in connection with calcium, magnesium, and sodium. He and his co-workers have found that some stream sediments when treated in certain ways will yield extracts of organic materials. When treated in other ways, the organic material apparently is retained and cannot be readily removed. These phenomena are poorly understood, and further research is necessary before much will be known about them.

SESSION 2

TYPES OF CONTAMINANTS

Chairman: W. E. Gilbertson

Biological Contamination of
Ground Water, W. L. Mallman and W. N. Mack . . . . Page 35

Inorganic Chemical Contamination of Ground Water, W. J. Kaufman . . Page 43

Organic Chemical Contamination of
Ground Water, F. M. Middleton and G. Walton . . . . Page 50

Experiences in the Netherlands on
Contamination of Ground Waters, J. K. Baars . . . . Page 56

Discussion . . . . Page 62

BIOLOGICAL CONTAMINATION OF GROUND WATER

W. L. Mallmann and W. N. Mack, Michigan State University

Any review pertaining to biological contamination of ground water should be prefaced with the statement that the accrued information on this subject is excellent background but may not answer problems on present or future ground water contamination. The chemical nature of the waste waters has changed, and there are no experimental tests on the migration of viruses in ground water.

A review of the literature will reveal in part the distance pollution travels, as indicated by bacterial contaminants in laboratory demonstrations, planned field tests, and epidemiological surveys of water-borne diseases. Without question a health problem exists, particularly in suburbia where common water supplies and sewerage systems have not been installed. Unless recognition is given to the problem and proper specifications based on research are formulated for the recharging of the ground aquifers, health hazards may result. These specifications should cover the introduction of sewage effluents by seepage from a septic tank drainage field, flooding of the soil, or pumping of water directly into aquifers for storage purposes. The behavior of biological contaminants in discharges entering agricultural soil may be different from that of [illegible] entering deep aquifers that contain small numbers of microorganisms and relatively small amounts of organic matter. Biological, chemical, and physical behavior may be totally different during both initial and prolonged discharges.

No attempt is made here to review all reports of bacterial contamination of potable water supplies through ground water pollution, but pertinent papers are reviewed to establish the fact that health hazards exist in ground waters as a result of travel of microorganisms from points of contamination and to show the need for protection of ground waters to be used for domestic and municipal purposes.

The need for restoring ground water tables by flooding the surface of the ground, by irrigation, and by recharge of aquifers is well established. What kinds of used waters may be reused, the degree and kinds of contaminants that may be tolerated, and the location of such operations in relation to wells for potable water must be determined. This paper is concerned only with microbial contaminants.

The danger of contamination of wells by seepage from earth privy vaults was recognized before the discovery of the microorganisms responsible for disease. In the famous cholera epidemic of 1854 in London, Dr. John Snow (1), in a carefully conducted epidemiological survey, established that the victims had used water from the Broad Street well for drinking water. In the house nearest the well, there had been four fatal cases of cholera at the time of the epidemic, in addition to earlier obscure cases that might have been cholera. Sewage from this house emptied into a cesspool near the well. Mr. J. York (1), surveyor of the inquiry committee, studied the well structure and its surroundings. He found a broken sewer line 2-3/4 feet from the wall of the well a foot above water table and, at a short distance from the well, a small cesspool fully charged with sewage. Without question, it was demonstrated that seepage from the drain and the cesspool entered the well.

An investigation of an epidemic of typhoid fever that occurred in Lausen, Switzerland (1), in 1872 was conducted in a novel manner. A brook was contaminated by wastes from a typhoid patient in a neighboring valley that was separated from the village by a high hill. Tests with sodium chloride (1800 lb) demonstrated that the water from the brook fed springs in the village. Later 5000 pounds of finely ground flour was added to the brook; none was detected later in the village springs, indicating that particles as large as starch granules were removed by filtration.

In 1909, Ditthorn and Luerssen (2) reported on the passage of bacteria through soil in Germany. A test well was drilled to a depth of 62 feet below water table at a spot 60 feet from a 177-foot well in which water collection started at 121 feet. *Serratia marcescens* was introduced into the test well, along with enough water to raise the ground water table 3 to 4-1/2 feet. At the same time the second well was pumped heavily. Samples of water were collected daily and examined for *S. marcescens*. Organisms were detected on the ninth day and for 10 successive days thereafter. No organisms were detected 19 days after the last injection.

In the early twenties, the senior author (3) made a study of a contaminated well located approximately 30 feet from a septic tank tile field. To determine the role of the septic tank in the pollution, the well and the septic tank effluents were checked for the presence of *S. marcescens* but none was detected. A gallon of *S. marcescens* culture was added to the siphon chamber of the septic tank. Two small test wells were drilled at 10-foot intervals between the well and the septic tank. After the seeding, daily samples of water from the test wells and the study well were collected and tested. The *S. marcescens* was detected in the test well adjacent to the tile field in 2 days, in the second test well in 3 days, and in the study well in 10 days. The source of pollution was well established.

A very excellent study of the migration of bacterial pollutants from sewage-flooded trenches was made in 1923 by Stiles and Crohurst (4). They demonstrated that bacterial pollution was largely at the interface between the ground water surface and the capillary water zone. The bacteria traveled 232 feet, whereas a fluorescent dye, uranin, traveled 450 feet. The pollution traveled primarily in the direction of the ground water flow.

In Alabama in 1937, Caldwell and Parr (5) investigated the migration of bacteria, as measured by coliform organisms, from a bored-hole latrine that penetrated below the water table. Initially coliform organisms traveled 15 feet in 3 days. After 3 months of continued use of the latrine, 90 percent recovery was made at 15 feet, 40 percent at 25 feet, and only an occasional positive sample at 35 feet. Chemical pollution traveled farther than the bacteria. The travel of pollution was only in the stream flow. The width of flow of bacterial pollution was 3 feet at a distance of 15 feet, whereas the spread of chemical pollution was 5 feet at 25 feet. The significant finding in this study was the demonstration of a barrier to the spread of microbial contamination; this barrier, formed by the deposition of particulate material at the periphery of the latrine, functioned as a filtering mechanism.

Caldwell (6) in 1938 made a study of a pit latrine located in an area where an impervious stratum closely underlies the ground water. Under these conditions the coliform organisms traveled 40 feet in less than 3.5 days. Organisms were detected in the ground water at a distance 80 feet downstream. In 1938 Caldwell (7) also investigated pollutant migration from a pit latrine located in an area where permeable soil existed for a considerable distance below the pit. In 3 to 4 months the coliform organisms had migrated only 10 feet; at the termination of the study, the migration distance had regressed to 5 feet. On the other hand, gross chemical pollution progressed 80 feet in the flow stream and some chemicals were detected as far away as 325 to 350 feet.

McGauhey and Krone (8) in 1954 made a very extensive study of aquifer contamination by introducing sewage-degraded water and following bacterial contamination through a series of test wells spaced along the water flow in the aquifer. Tests were made for both coliform organisms and enterococci. Daily observations were made for 41 days. The coliform counts from Table 14 of their report follow:

Well location	Coliform count, MPN per 100 ml		
	Average	Maximum	Minimum
Initial	2.4×10^6	2.4×10^8	2.4×10^4
10 ft	2.4×10^5	2.4×10^6	95
25 ft	2.4×10^5	2.4×10^6	2.4×10^4
50 ft	2.4×10^3	2.4×10^4	0
100 ft	23-38	38	2

It was observed that both enterococci and coliform organisms migrated equally well in the aquifer. Coliform organisms were the better indicators only because they occurred in larger numbers in the original degraded water. After continued recharging, a regression of indicator bacteria occurred. This was believed to have been caused by death of the bacteria in the aquifer with exposure time and by the increased filtering action of particulate material deposited in the aquifer at the point of entry.

This study indicates that recharging can be done without grossly polluting the aquifer with disease-producing bacteria. The findings are, of course, limited to situations comparable to those in the experiments reported. The results are encouraging in that bacteria occurred only in the test wells in the immediate vicinity of the recharging well.

In 1957, Fournelle, Day, and Page (9) reported on a study somewhat comparable, except that the ground water table was between 5 and 6 feet below the surface of the ground. The dosing well was sunk into the ground water, and the test wells were 8 to 10 feet deep. Uranin was used in measuring chemical travel and was found up to distances of 100 feet. The path of the dye initially was only 1-1/2 to 4 feet wide, but after several years the wedge widened to 40 feet at the most distant point. Bacterial contamination, as measured by enterococci, migrated only 50 feet in a path of travel 1-1/2 to 4 feet wide. In this study, the water contained only the test organisms. If organic matter had been present, the travel might have been shorter.

A study was made by Baar (10) in 1957 in the Netherlands of travel of microorganisms in sandy soils with a particle size of 0.17 mm and a uniformity coefficient of 1.65 mm. With heavy pollution from pit latrines in dry soil, coliform organisms penetrated to depths of 120 inches. A nitrogen measurement showed that when pollution ceased, the nitrogen content decreased rapidly and self-purification occurred. When ground waters were recharged with relatively clean water, vigorous adsorption of organic matter and bacteria occurred in the upper 10 feet of soil. When free oxygen was introduced with the water, rapid mineralization occurred. It was reported that if the oxygen supply was not sufficient, anaerobic conditions developed. To avoid anaerobic conditions, the BOD content of the water must be reduced or intermittent infiltration must be used. When pollution was introduced into soils with high ground water levels, contamination remaind for long periods of time. Numerous articles in the literature reaffirm the results of the studies cited. A recitation of these references would serve only to document further the facts that bacteria migrate particularly in the direction of ground water flow, that because of adsorption on soil particles and the straining action of the substratum travel is limited in distance, that this distance is determined in part by the rate of ground water flow and the particle size of the substrate, and that the amount and kind of suspended material in the recharge water will determine the travel distance by forming a filtering barrier at the point of entry.

In contrast to these very excellent research projects under experimental conditions, outbreaks of disease have occurred where migration distances have been much greater than those reported in the experimental studies.

Warrick and Tully (11) report an epidemic in 1930 of 1100 cases of dysentery and typhoid caused by polluted river water entering an abandoned well. The pollution traveled to city wells located 800 feet away. To prove that the abandoned well was responsible, salt was introduced into the abandoned well. Seventeen hours later the salt was detected in the city wells.

Weber (12) reported in 1958 an outbreak of hepatitis resulting from well waters polluted by sewage effluent disposed of by seepage. Prior to this disposal by seepage, the wells in the area had been examined. Some were faulty in construction and some were unsatisfactory, as measured by bacterial tests; however, chemical examination had revealed no evidence of pollution. Six months after seepage began definite deterioration of the well waters was detected chemically - color tests showed contamination in one well 1 day, in another 3 days later, and in a third after another month. The first well was not used after seepage disposal was started. Hepatitis occurred in families using the well waters that chemical tests showed were polluted.

In Russia in 1955 Yanovich et al. (13) reported 73 cases of leptospirosis. The epidemic was caused by water from a faulty water tower contaminated by underground water that had been contaminated from the surface by heavy rains.

Clark and Chang (14) in 1959 listed the following epidemics of infectious hepatitis caused by contaminated ground water:

1944 - 350 cases - driven well polluted by a cesspool 75 feet away.

1952 - 22 cases - drilled well polluted by cesspool 50 feet away.

1952 - 102 cases - spring polluted from a broken sewer; contamination traced by dye.

1956 - 18 cases - well polluted by septic tank effluent.

1956 - 46 cases - well polluted by a river 50 feet away.

Again a citation of epidemics caused by viruses carried in sewage-contaminated ground water would only document further the fact that viruses can be carried through ground waters for considerable distances from points of contamination. It is not intended that this paper present a complete literature review; the citation of epidemics of bacterial and viral origin is presented to show that sewage contamination of ground waters can and does occur, making water supplies health hazards.

Although no documented rural epidemics other than hepatitis have been reported, it has been amply demonstrated (14, 15, 16, 17, 18, 19, 20, 21, 22) that viruses are carried in sewage. Bloom et al. (23) in an examination of 1018 sewage samples over a 29-month period isolated a total of 150 viruses. Thirty-one were identified as enteric cytopathogenic human orphan (Echo) viruses, 4 as polio viruses, 76 as Coxsackie viruses; 17 were not identified, and 22 were lost on tissue culture passage or storage. It is impossible at this writing to show, either by records of epidemics or case reports, proved spread of these viruses by sewage contamination of water, even where gross pollution has occurred. This does not mean that transmission has not occurred. Until the relationship of many of these viruses to disease in man has been established, epidemiological surveys cannot be made. In the meantime, good public health practices reduce contamination of water supplies by sewage or sewage effluents. This has been demonstrated by the use of bacterial indicators such as coliform organisms as yardsticks of pollution.

The use of chlorinated sewage effluents as reuse water, either surface or underground, is still questionable. During a severe water shortage in Chanute, Kansas (24), reclaimed water was used as a municipal supply. Complete treatment of the sewage effluent was made, including chlorination. Two positive isolations of virus were made from unchlorinated sewage plant effluent; however, the techniques available for virus detection are far from dependable even for qualitative determinations. At Chanute there was no unusual incidence of disease that might be attributed to the water supply. In epidemiological evaluations of this experience it must be remembered that the population was not disposed to enjoying a "head" on a glass of drinking water, caused by the presence therein of synthetic detergents (syndets). The reminder that the water was reused deterred many people from consuming the "beverage." The sale of bottled water was high.

Viruses are not easily destroyed by chemical agents. Weidenkopf (25) studied quantitatively the destruction of purified poliomyelitis virus (Mahoney type 1) by free chlorine at pH 6, 7, and 8.5. To attain destruction of 1000 plaque-forming units (pfu) in 2.5 minutes, 1.65 ppm free chlorine at pH 6 was necessary; at pH 7 in 10 minutes, 0.53 ppm; and at pH 8.5 in 10 minutes, 5.0 ppm.

Neefe et al. (26) in 1945 reported a series of experiments in which infectious hepatitis fecal samples were diluted to 55 ppm fecal material. This solution was treated with hypochlorite to yield a residue of 1 ppm free chlorine in one series of experiments and a free chlorine residual of 15.23 ppm in a second experiment. In each series, the contact time was 30 minutes and 10 volunteers were used, 5 received the untreated water and 5 the chlorinated water. In the first series, two of each group became infected, indicating that the chlorination was ineffective. With the higher chlorination treatment, those using chlorinated water did not become infected whereas four of the five receiving the untreated water were infected.

Other research workers (27, 28, 29, 30, 31, 32, 33) have presented results that show viruses, with some exceptions, are more resistant to chlorination than bacteria such as Escherichia coli.

Mack and Frey (34) in 1961 found that enteric viruses survived chlorination of sewage effluent from an activated-sludge plant. Although a diminution of virus particles occurred, as measured by the incidence in the secondary settling tank effluent and the chlorinated effluent, the surviving numbers are significant.

Many reports have been presented on the survival of coliform organisms in the soil (35, 36, 37, 38, 39). Although the times of survival depended largely upon the plan of the experiments, in general it was found that coliforms, both *E. coli* and *A. aerogenes*, survived for periods up to 4 years, the duration of the longest experiment (40). It was also demonstrated that coliforms retained their cultural, morphological, and physiological characteristics throughout the experiments.

Survival of *Salmonella typhosa* innoculated into soil, however, was of short duration. In 1905 Mair (41) found that this survival was dependent on the source and strain of the organism. He reported survival periods in soil of 29 to 58 days. Creel (42) in 1912 found that under ideal conditions the typhoid bacillus survived only 31 days in soil. In 1951 Mallmann and Litsky (43) in a comparative study of different type soils found that *S. typhosa* died out in less than 48 days. Survival was longest in soils with high organic content. Survival in Oshtemo sand was less than 8 days and in muck less than 19 days. In contrast, coliform organism diminished in all soils in 11 weeks but were still present in large numbers, whereas enterococci in the same experiments disappeared from Oshtemo sand in 6 weeks (shortest period) and from Brookston clay loam in 11 weeks (longest period). Wade (44) in 1950 found that *S. typhosa* did not survive more than 2 weeks in Oshtemos sand and 6 weeks in muck without loss of VI antigen, which indicates retention of virulence by the organism.

Measuring the health hazard of contaminated ground waters by means of coliform organisms is unreliable except when negative results are obtained. The presence of coliform organisms is not necessarily an indicator of pathogenic bacteria such as *S. typhosa*. This method would not be dependable for measuring *Mycobacterium tuberculosis*, which persists for extremely long periods. Enterococci would be better indicators of health hazards in ground waters, since their persistence in soils is not much greater than that of pathogenic bacteria.

The viability of viruses in soil and ground water is not known. Experiments should be made to determine their persistence and the extent of their migration in ground water.

In all the studies, no consideration was given to the presence of syndets in present day sewage. There is no need here to review the literature as it pertains to the amounts and kinds of syndets, but they are present in all sewage, including household and municipal wastes.

Syndets lower the surface tension of the sewage, thus allowing a more rapid movement of water through the soil, particularly through dry soil. Since they are also good suspending agents, small particles such as bacteria and viruses are suspended and carried through porous soil with little deposition; the degree of deposition is dependent upon the concentration of the syndet and the amount of suspendable solids.

Wells in many suburban areas where septic tanks with tile fields are used are becoming contaminated with syndets, as demonstrated by foam on water drawn from the tap. Such situations exist in Michigan, particularly where the soil is sandy and the water tables are high. Steps are being taken to eliminate the health hazard in these areas by provision of muncipal water supplies and installation of sewers to replace the septic tanks.

No dependable epidemiological surveys have been made to measure disease incidence in these areas; however, it is certain that sewage is entering the well waters. If hepatitis has not occurred already, the situation certainly has been prepared for the introduction of the hepatitis virus or any other pathogen transmissible through fecal discharges. Syndets in the sewage are not only good indicators of sewage pollution but are probably good virophores and perhaps bacteriophores.

If sewage effluents are to be used for recharging aquifers, either by percolation or deep well recharge, the recharge water should have low biochemical oxygen demand and high dissolved oxygen content if introduced directly into aquifers. This would avoid the development of anaerobic conditions, which cause a rapid blocking of the voids in the porous soil, formation of objectionable biochemical by products, and little digestion of the syndets. If the dissolved oxygen is in excess of the biochemical oxygen demand, mineralization will result, the straight chain arylsulfates will be destroyed, and the porous aquifer will not be blocked by undigested organic matter.

SUMMARY

Field studies in which test wells surround a recharging well that receives diluted sewage effluent have indicated that:

1. Polution spreads from the recharging well in the direction of water flow in the aquifer.
2. Bacteria seldom migrate more than 100 feet from the recharging well, and then only during the early phase of aquifer recharge.
3. Particulate material in the recharge water deposits at the point it enters the aquifer, forming a filtering substratum that tends to retain bacteria. As a result bacteria migrate only a few feet from the filtering substratum forms.
4. Inporous soils with low water tables, bacteria disappear from the aquifer soon after recharging ceases.
5. Soluble substances in the recharge water travel farther than the bacteria.
6. Bacteria are removed from the recharge water in the aquifer by adsorption on soil particles and by filtration (straining action) of the particle mass.

Surveys of sources of epidemics due to ground water contamination indicate that in many cases bacteria have traveled much greater distances than those recorded in experimental tests.

Pollution of ground water that has caused epidemics has been the result of sudden gross contamination, a situation comparable to the first rush of bacteria through an aquifer before a filtering substratum has developed at the point of entry.

Syndets in sewage lower the surface tension of the water, causing it to wet the substrate so that passage may be more rapid. Syndets are good suspending agents with the result that bacteria may be carried farther in the soil without deposition. No studies in which syndets had been tested to prove this statement were found in the literature.

Virus diseases have been caused by contaminated ground water. No field tests have been made to determine the travel of viruses in ground water. Laboratory tests demonstrate that viruses are generally more resistant to chlorine treatment than bacteria. Field tests demonstrate that viruses pass through complete sewage treatment processes and survive sewage effluent chlorination, as routinely practiced in sewage treatment plants.

The duration of survival in the soil of pathogens such as salmonellae is dependent upon the nature of the soil, the pH, the temperature, and the moisture and salt content. Most pathogens die out rapidly in ground water.

There is no information available on the period of survival of viruses in ground waters, although the writers believe this time period is relatively short.

Endemic pollution of ground water may occur in heavily populated suburban areas where numerous septic tank fields are flooding the ground water table.

REFERENCES

1. Prescott, S. C. and Horwood, M. P. Sedgwick's Principles of Sanitary Science and Public Health. The MacMillan Company, New York, pp. 652, 1935.

2. Dilthorn, F. and Luerssen, A. Experiments on the passage of bacteria through soil. Eng. Rec. 60, 642, 1909.

3. Mallmann, W. L. Unpublished data.

4. Stiles, C. W. and Crohurst, H. R. Principles underlying the movement of B. coli in ground water with the resultant pollution of wells. Pub. Health Rep. 38: 1350, 1923

5. Caldwell, E. L. and Parr, L. W. Ground water pollution and the borehole latrine. Jour. Inf Dis. 61: 148. 1937.

6. Caldwell, E. L. Pollution flow from pit latrines when an impervious stratum closely underlies the flow. Jour. Inf Dis. 61: 270, 1937.

7. Caldwell, E. L. Pollution flow from a pit latrine when permeable soils of considerable depth exists below the pit. Jour. Inf. Dis. 62:225, 1938.

8. McGauhey, P. H. and Krone, R. B. Report of investigation of travel of pollution. Calif. State Water Poll. Bd. Publ. 11, pp. 218, 1954.

9. Foursalle, H. J., Day, H. K. and Page, W. E. Experimental ground water pollution at Anchorage, Alaska. Pub. Health Rep. 72: 203, 1957.

10. Baars, J. K. Travel of pollution and purification enroute in sandy soils. Bull. World Health Organ. 16: 4, 727, 1957.

11. Warrick, L. F. and Tully, E. J. Pollution of abandoned well causes Fond du Lac epidemic. Eng. N. R. 104: March 6, 1930.

12. Weber, G. Chemical and bacteriological investigation of ground water during an epidemic of hepatitis. Osterr. Wasser (Austria) 10: 110, 1958. Pub. Health Eng. Abst. 39: 11, 27, 1959.

13. Yanovich, T. O. et al. Leptospiroses of the canicola type in one of the regions of Rostov on Don. Zhur. Mikrobiol. 2: 100, 1957. Sewage and Ind. Waste, 31: 763, 1959.

14. Clarke, N. A. and Chang, Shih L. Enteric viruses in water. Jour. A. W. W. A. 51: 1299, 1959.

15. Paul, J. R., Trask, J. D. and Culotta, C. S. Poliomyelitis virus in sewage. Science 90: 258, 1939.

16. Paul, J. R. Trask, J. D., and Gard, S. Poliomyelitis in urban sewage. Jour. Exp. Med. 71: 765, 1940.

17. Trask, J. D., Paul, J. R., and Vignec, A. J. Poliomyelitis virus in human stools. Jour. Exp. Med. 71: 751, 1940.

18. Levaditi, C. On the presence of poliomyelitic virus in sewage. Bul. Acad. Med. 123: 335, 1940.

19. Clarke, E. M. et al. Coxsackie virus in urban sewage. Can. J. Pub. Health 42: 103, 1951.

20. Kelly, S. M. Detection and occurrence of coxsackie viruses in sewage. Am. J. Pub. Health, 43: 1532, 1953.

21. Clarke, N. A., Stevenson, R. E. and Kahler, P. W. Survival of coxsackie virus in water and sewage. Jour. A. W. W. A. 48: 677, 1956.

22. Mack, W. N., Mallmann, W. L., Bloom, H. H. and Krueger, B. J. Isolation of enteric viruses and salmonellae from sewage. Sew. & Ind. Wastes 30: 957, 1958

23. Bloom, H. H., Mack, W. N., Krueger, B. J., and Mallmann, W. L. Identification of enteroviruses in sewage. Jour. Inf. Dis. 105: 61, 1959.

24. Metzler, D. F. et al. Emergency use of reclaimed water for potable supply at Chanute, Kansas. Jour. A. W. W. A., 50: 1021, 1958.

25. Weidenkopf, S. J. Inactivation of type 1 poliomyelitis virus with chlorine, Virology 5: 56, 1958.

26. Neefe, J. R., Stokes, Joseph, Baty, J. R., and Reinhold, J. G. Disinfection of water containing causative agent of infectious (epidemic) hepatitis. Jour. A.M.A. 128, 15, 1076, 1945.

27. Trask, J. D., Melnick, J. L. and Wenner, H. H. Chlorination of human, monkey adapted, and mouse strains of poliomyelitis virus. Am. Jour. Hyg. 41: 30, 1945.

28. Ridenour, G. M., and Ingols, R. S. Inactivation of poliomyelitis virus by free chlorine. Am. Jour. Pub. Health. 36: 639, 1946.

29. Lensen, S. G., Rhian, M. and Stebbins, M. R. The inactivation of partially purified poliomyelitis virus in water by chlorination. Jour. A. W. W. A. 38: 1069, 1946.

30. Lensen, S. G., Rhian, M. and Stebbins, M. R. The inactivation of partially purified poliomyelitis virus in water by chlorination. Am. Jour. Pub. Health 37: 869, 1947.

31. Lensen, S. G. et al. Inactivation of purified poliomyelitis virus in water by chlorination. Am. Jour. Pub. Health 39: 1120, 1949.

32. Clarke, N.A. and Kabler, P. W. The Inactivation of purified coxsackie virus in water by chlorine. Am. Jour. Hyg. 59: 119, 1954.

33. Kelly, S. and Sanderson, W. W. The effect of chlorine in water on enteric viruses. Am Jour. Pub. Health, 48: 1323, 1958.

34. Mack, W. N., and Frey, James. Unpublished data, 1961.

35. Savage, W. C. Bacterial examination of tidal mud as an index of pollution of river. Jour. Hyg. 5: 146, 1905.

36. Revis, Cecil. The stability of physiological properties of coliform organisms. Cen. f. Bakt. 11 ABT. 26, 161, 1910.

37. Young, C.C. and Greenfield, H. Observations on the viability of the Bact. Coli group under natural and artificial conditions. Am. Jour. Pub. Health. 13: 270, 1923.

38. Skinner, C. E. and Murray T. J. The viability of B. coli and B. aerogenes in soils. J. Inf. Dis. 38: 37, 1926.

39. Tonney, F. O. and Noble, R. E. The relative persistence of Bact. coli and Bact. aerogenes in nature. J. Bact. 22: 433, 1931.

40. Kulp, W.C. A note concerning the effect of a specific environment on the characteristics and viability of several strains of A. aerogenes and E. coli. J. Bact. 24: 317, 1932.

41. Mair, W. Experiments on the survival of B. typhosus in sterilized and unsterilized soil. J. Hyg. 8: 37, 1908.

42. Creel, R. H. Vegetables as a possible factor in the dissemination of typhoid fever. Pub. Health Rep. 27: 187, 1912.

43. Mallmann, W. L. and Litsky, Warren. Survival of selected enteric organisms in various types of soil. Am. Jour. Pub. Health. 41: 38, 1951.

44. Wade, Sarah T. The persistence of the VI Antigen of Salmonella typhosa. M.S. thesis Michigan State University, E. Lansing, Mich. 1950.

INORGANIC CHEMICAL CONTAMINATION OF GROUND WATER

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The inorganic chemical contaminants of ground water differ from organic and biological contaminants in many ways, the most important differences being their indestructibility, the persistence of pollution resulting from their presence, and the great difficulty and cost of their abatement. It is possible to cite numerous instances of small concentrations of toxic inorganics that appeared in ground water and impaired its acceptability for domestic use. It is probable that the major impact of inorganic contamination is not on man's health but rather on his agricultural and industrial enterprises, i.e., his pocketbook, and frequently stems from the excessive mineralization associated with intensive beneficial use. Thus, the problem of deteriorating ground water quality is merely the price, often delayed, that we must pay for the use and reuse of this essential natural resource.

This review deals in a general way with the effects, origins, and modes of transport of inorganic pollutants, omitting detailed enumeration of specific cause and effect situations. Numerous authors, particularly McKee (1) in 1952 and 1954, have presented collations of water quality information that are available to the practitioner and cannot be improved upon by summarization or fragmentation in this short presentation. A brief discussion of inorganic water quality criteria as they relate to the three major user categories -- domestic, agricultural, and industrial--may provide a perspective of our objectives however and help avoid an overly simplified treatment of this very complex problem.

INORGANIC QUALITY REQUIREMENTS

The Domestic Consumer

The Public Health Service Drinking Water Standards of 1946 specify limits for certain inorganic chemicals in water, distinguishing between mandatory and recommended limits. A noteworthy addition to the mandatory drinking water requirements is the U.S. Atomic Energy Commission's Standards for Protection Against Radiation (2) as made effective January 1, 1961. A majority of the states have adopted the 1946 Standards as requirements for public water supplies within their jurisdictions, and these standards are, of course, applicable to interstate common carriers in accordance with federal law. The 1961 federal radiation standards establish mandatory limits for radioisotopes in water; however since these standards implement the Atomic Energy Act of 1954, they are intended only for protection against hazards arising from uses of radioisotopes under licenses issued by the Atomic Energy Commission. Undoubtedly, these standards or modifications thereof will in time be incorporated into the Public Health Service Standards and will apply to radionuclides from all sources.

Since the mandatory chemical standards are intended to protect the domestic consumer's health, they deal with the relatively toxic constituents of water. For the most part, these standards are supported by only the most tenuous epidemiological data, but since the toxic substances are rarely encountered in ground waters, there are only a few instances where the standards have not been met. The situation is further ameliorated by the safety factors employed in fixing specific values. It should be recognized, however, that often great variance exists in population sensitivity to toxicants, and threshold effects difficult to identify may influence many persons to a small degree before the causal agent has been identified. It might be interesting to inquire into the frequency of routine analysis for heavy metals performed by a typical community served by a ground water supply.

In many respects, radioactivity contamination poses health problems analogous to those that evolve from chemical contamination. As the sensitivity of detection of radiation effects advances, the biophysicist is able to perceive subtle changes in human physiology brought about by ever-decreasing amounts of radiation exposure. One school of thought frequently expressed by Jones (3) contends that no threshold exists in the relationship of radiation dose to radiation effect, even in somatic effects, and that life-span shortening may bear a linear relation to dose, with about 10 days per roentgen being the constant of proportionality. Although absolute epidemiological proof of such a relationship may never be demonstrated, those responsible for establishing standards of water quality must certainly take cognizance of these small but potentially very significant consequences of nuclear energy developments. In addition, as other participants in this Symposium will doubtless observe, subtle and hardly detectable stresses on the human body are very likely to result from the many other activities of man in our complex industrial society.

Thus, safety and health are relative and the establishment of domestic water standards in many particular instances must ultimately take into full account the realistic but unpopular risk-benefit equation if we are to regulate our water resources with some modicum of rationality.

Irrigated Agriculture

In the 17 western states, concern for inorganic chemical contamination is most closely related to agricultural water quality needs. Here again, it is not possible to establish absolute levels of quality; rather, we must recognize the complex cost-benefit relationship between specific agricultural uses and the water qualities available.

Dr. L. V. Wilcox of the U.S. Salinity Laboratory (4) has cited four quality criteria that ordinarily cover a majority of the irrigation applications: Total salt concentration, sodium, boron and other toxic substances, and bicarbonate. Although it is desirable to irrigate with waters that have dissolved solids in the range of 150 to 500 ppm, it is possible, though not nearly as economical, to use water with up to 3000 or 4000 ppm. An increasing number of irrigators are finding the latter practice necessary for continued agriculture. Crop yields are often less with such waters, and annual water needs are greatly increased if salt buildup in the plant root zone is to be avoided. Sodium, though itself not especially toxic, may adversely affect the physical properties of a soil, indirectly reducing crop yields and increasing the requirements for water and special soil amendments. Excessive concentrations of bicarbonate may lead to calcium carbonate precipitation and further aggravate the sodium and over-all salinity problem by increasing the sodium adsorption ratio (SAR) with accompanying tightening of the irrigated soil.

Boron is the most commonly encountered toxic inorganic chemical, and its presence in an aquifer may restrict severely the range of agricultural development possible. Although a trace is required for all plants, many plants (e.g., the citrus group) will not tolerate more than 1 ppm and few crops are produced economically with concentrations in excess of 3 or 4 ppm.

Table 1. QUALITATIVE CLASSIFICATION OF IRRIGATION WATERS

Class	Chemical constituents			
	Total dissolved solids, ppm	Chloride, ppm	Sodium, % *	Boron, ppm
I. Excellent to good	>700	>175	>60	>0.5
II. Good to injurious	700-2000	175-350	60-75	0.5-2.0
III. Injurious to unsatisfactory	>2000	>350	>75	>2.0

*Sodium, % = $\left(\frac{Na}{Na + Ca + Mg + K}\right)$ 100, where bases are expressed in milliequivalents per liter.

Table 1 shows the qualitative classification of irrigation waters used by the California Department of Water Resources (5) and indicates the broad range of compositions from "excellent" to "unsatisfactory." Class I water is suitable for nearly all plants under any soil and climatic circumstance, whereas Class III water is harmful to most crops and unsatisfactory for all but the most tolerant. Other factors being equal, the volume requirements of Class II water would be appreciably greater than those of Class I, if salt balance is to be maintained.

Industry

Industry as a whole has such varied water quality requirements that it is virtually impossible to establish generally applicable criteria. Even in particular industries attempts to analyze needs are often of limited value because of variation in the types of processes, the raw materials used, and the final products. Process waters often have the highest and most specific quality requirements, since product quality may depend on close control of certain constituents, e.g., iron and manganese in the pulp and paper industry. Water quality may also influence the deterioration of process equipment, leading to incrustation or corrosion and increased maintenance and replacement costs, with concomitant reduction in efficiency. Boiler water has relatively well-established quality requirements, which for high pressure systems are so restrictive that the water requires conditioning in almost all instances. Cooling water, on the other hand, has relatively limited quality restrictions, other than temperature, and generally poses no special problems.

Pearson (4, pp. 126-135) concluded that no single set of water quality criteria is applicable to both municipal and industrial uses and that it is impractical to consider uniform quality standards for industry as a whole or even for a specific type of industry. Individual situations must be appraised individually to ascertain their particular requirements.

ORIGIN OF INORGANIC GROUND WATER CONTAMINANTS

For purposes of this discussion, the terms contaminant and pollutant will be used synonymously to designate any substance in water that has been altered directly or indirectly by man and that might detract from the value of the water in some subsequent use by man.

There are numerous ways in which municipal sewage and industrial wastes directly impair the mineral quality of ground water. A survey completed in 1960 by Task Group 2450R of the American Water Works Association (6) listed waste disposal wells and lagoons, leaking chemical storage tanks, and cesspools as the most often reported sources of contamination. The most commonly reported inorganic contaminants were salt water, oil-field brines, and sodium chloride, with an occasional report of specific toxic agents such as fluoride, chromium, and nitrate. In most instances, little difficulty was encountered in establishing the particular origin of the more toxic contaminants.

In many states the two most important causes of extensive inorganic contamination are sea water intrusion and deep percolation from irrigated agriculture. In each instance of sea water intrusion, the cause was overpumping for which the only long-term solution is importation of additional water from other basins. In certain situations, e.g., in the Manhattan Beach - Hermosa Beach area of Southern California, it has been possible to retard sea water intrusion by creation of fresh water barriers through the operation of injection wells. Unless the overdraft on aquifers discharging beneath the sea is reduced or redeemed by the recharged waters, such barriers must ultimately fail.

Ground Water Quality and Irrigation Practices

The influence of irrigation practices on ground water quality is far more serious than sea water intrusion and is creating problems in a majority of the important river basins in the western states. Generally, about two-thirds of the irrigation is used consumptively, being returned to the atmosphere by evaporation and transpiration. The remainder, enriched in salts by the evapotranspiration process, by leaching of fertilizer, and by accretions of carbon dioxide, percolates down to the ground water table. To avoid salt buildup, the irrigator must apply sufficient water to transport these salts from the root zone of his crop. Generally, these salts are moved to a nearby stream or appear in the wells of neighbors. Subsequent users of the water are faced with an even greater salinity problem and must apply increasing quantities of water to their lands to maintain the essential salt balance.

F. M. Eaton's (7) report on salinity conditions in a portion of the Rio Grande Valley is an excellent example of the close relation of surface and ground water quality to irrigation practice. Wells drilled in the valley floor generally have been too saline to support agriculture, but upon completion of the Elephant Butte Dam, a flourishing irrigated agriculture developed. The buildup of salinity in the Rio Grande River, largely from irrigation return water and base flow and perhaps augmented by displaced deep local ground waters, is seriously threatening agriculture in this region however. This is illustrated by the data in Table 2, which indicate the salt balance between the Elephant Butte Reservoir and Fort Quitman, a 200-mile reach of the Rio Grande Valley.

In 1946, releases from Elephant Butte amounted to 830,000 acre-feet of water, of which only 16 percent reached Fort Quitman. In 1951 reservoir releases amounted to only 429,000 acre-feet, and less than 6 per cent reached Fort Quitman. Whereas in 1946 only 16 percent of the input salts were retained, by 1951 over 7,800 ton-equivalents, or 72 percent, remained in the valley. Furthermore, although Elephant Butte discharges had

Table 2. SALT BALANCE BETWEEN ELEPHANT BUTTE RESERVOIR AND FORT QUITMAN, RIO GRANDE RIVER[a]

	Salt releases					
	1946			1951		
	Elephant Butte, T.E.[b]	Fort Quitman, T.E.[b]	Salt retained, %	Elephant Butte, T.E.[b]	Fort Quitman, T.E.[b]	Salt retained, %
Cations						
Calcium	3283	1869	43	2005	358	82
Magnesium	1140	741	35	763	179	77
Sodium	3241	4037	-25	2486	898	63
Anions						
Bicarbonate	3071	706	77	1728	101	94
Sulfate	3584	2080	42	2327	438	81
Chloride	1208	3744	-210	1342	957	29
	15467	12886	16	10600	2975	72

[a] Source: Reference (3).
[b] Ton Equivalents.

Table 3. ION-EXCHANGE SOFTENING IN THE LOS ANGELES SOUTH COASTAL BASIN

Constituent	TDS[a] composition, % by weight		
	San Gabriel River recharge	North-Central portion[b]	South-West portion[c]
Sodium - potassium	10.2	12.2	41.2
Calcium	20.2	28.3	7.7
Magnesium	10.6	9.2	1.3
Sulfate	7.3	6.1	7.3
Chloride	2.6	3.1	4.1
Bicarbonate - carbonate	39.9	41.6	38.3
Nitrate	0.2	0.2	0.2
TDS, mg/l	340	347	211

[a] Total dissolved solids.
[b] Depths; 680 to 900 feet.
[c] Depths; 586 to 1026 feet.

a favorable sodium percentage (62 percent), on reaching Fort Quitman the sodium percentage had reached a yearly average of 62 percent in 1946 and 64 percent in 1951. In 1951, 82 percent of the calcium was being retained in the valley fill and in large part had probably precipitated as the carbonate. It is evident that if agricultural enterprises are to be sustained in this region additional surface waters must be introduced to maintain or reduce salt buildup.

Ion-Exchange and Ground Water Quality

When water containing calcium, magnesium, and sodium is brought in contact with a soil, equilibrium is established between the cations in solution and those occupying ion-exchange sites in the soil clay fraction. If sodium is the predominant cation and if successive portions of high sodium water are passed down through a soil column, soil calcium is displaced and a sodium soil results. Such soils are often tight and have poor drainage qualities, necessitating liming to restore a favorable sodium percentage. The result is a percolating water containing at least one equivalent of calcium for each equivalent of sodium retained. A hard water of lower quality has resulted.

Ion-exchange may also serve to soften waters naturally, thus reversing the process described above. This phenomenon was illustrated by Morse (8) in a study of the Los Angeles South Coastal Basin in 1948. Waters of the San Gabriel River recharge the confined aquifers of this basin in the vicinity of the Montebello Forebay below the Whittier Narrows. The general direction of underground travel is toward the southwest, with ultimate discharge into the Pacific Ocean. Ion-exchange changes in mineral distribution during underground travel are clearly evidenced in Table 3.

The San Gabriel River water travels through nearly 10 miles of sedimentary formations, from the Montebello recharge area to the North-Central portion of the Los Angeles Basin, without significant change in composition. As the water reaches the south-west rim of the basin, however, samples taken from depths up to 1026 feet show a remarkably constant composition but with sodium rather than calcium as the predominant cation. Although the total equivalent concentration has not changed, the passing of the calcium bicarbonate water through formations containing sodium clays has resulted in a sodium bicarbonate water. Thus, the confined aquifers underlying the South Coastal Basin may be considered as enormous ion-exchange columns that are gradually being exhausted with the seaward migration of the calcium-magnesium water.

Radionuclides

Radioactivity is found to some extent in all ground waters, most often originating in the decay products of uranium-238 and, to a lesser extent, thorium-232, which are widely distributed in nature. Natural potassium includes 0.012 percent of the long-lived radioisotope potassium-40, which is readily detectable in waters high in alkali metals. Because of concern for water contamination by fission products of weapons-test origin or by wastes of the nuclear energy industry, numerous studies have been made to determine the natural background count of ground waters. Love (9) in 1951 and, more recently, Smith et al. (10) in 1960 reported the widespread occurrence of appreciable concentrations of radium-226 and its daughter products and presented extensive bibliographies pertaining to natural radioactivity. In analysis of 33 drilled wells in Maine, Smith found an average radon-222 concentration at the time of sampling of 17,000 μμc/l; the equilibrium value corresponding to the radium-226 concentration was 66 μμc/l. The maximum permissible concentration (MPC) of radium-226 from releases of radioactive liquid wastes to the environment, on a yearly average basis, is 10 μμc/l (2). It is evident that knowledge of the natural occurrence of radioactivity is important in exercising control over ground water quality, even though it may raise a rather difficult question when standards are set for protection of the consumer.

Except in the vicinity of nuclear energy installations, there is no evidence that man-made radioisotopes other than tritium, are contaminating ground water. At several of the sites operated under the jurisdiction of the U. S. Atomic Energy Commission, notably Hanford, Washington, and Oak Ridge, Tennessee, appreciable volumes of low- and intermediate-level radioactive wastes have been discharged to the earth, resulting in some contamination of aquifers within these government reservations. Straub et al. (11) have shown that a major fraction of the strontium-90 in the Tennessee River at Chattanooga had its origin at the Oak Ridge National Laboratory; over a major portion of the United States, however, the greatest source of this isotope is undoubtedly fallout from weapons testing.

To what extent are the nation's ground waters being contaminated by such fission products as strontium-90, and is this likely to become a serious matter? Straub et al. (11) have compared the strontium-90 in precipitation to that in runoff in the Ohio River Valley and have found an over-all retention of about 90 percent. This is equivalent to an annual retention (in 1959) of about 10,000 μμc/m^2. Since it is reasonable to assume that all of the deposited strontium will pass into solution, it is necessary to conclude that while currently accumulating at the soil surface, it also is being transported downward by infiltration of precipitation. Yet, samples of infiltrated rain water taken a few inches below the soil surface are almost completely free of strontium-90 if the surface layers have any significant ion-exchange capacity. It is thus evident that natural transport processes through the soil are extremely inefficient and that extended retention in surficial soils may be anticipated, at least if the course of events is left solely to nature.

There is ample evidence that little or no strontium-90 from fallout has reached ground water supplies that are adequately protected against direct surface water contamination. High radionuclide concentrations in surface streams are associated with intense precipitation and peak runoff, strongly suggesting that scrubbing of the atmosphere and transport of contaminated topsoil are the major contributors. At low stream flows, when the salt concentrations are generally highest because of ground water inflow, radionuclide concentrations attributable to fallout are at a minimum. Even wells in the vicinity of the

Nevada Test Site have shown no increase in radioactivity that could be attributed to deep percolation of fallout.

A specific hypothetical question may reveal whether we can expect all ground waters to remain essentially free of strontium-90. If it is assumed that over a 10-year period a total strontium-90 deposition of 80 mc/sq mi has occurred and that this strontium is held within a 5 cm layer of virgin soil with an exchange capacity of 5 meq/100 grams and further that the land is irrigated with water containing 2.5 meq/l calcium and applied at a rate of 4 feet per year, but with an evapotranspiration loss of 50 percent, what is the maximum concentration of strontium-90 ion that may be found in the percolating irrigation water? The strontium - calcium mass action constant describing the exchange equilibrium may be reasonably estimated at 1.5 (12). Under these conditions, the percolating irrigation water in equilibrium with the 5-cm soil layer would contain about 0.015 μμc/ml of strontium-90. This is a maximum value, since it was assumed that solution took place in only 1.75 cm of water whereas dilution would undoubtedly occur in a very much larger volume of applied water. The average strontium-90 percolation velocity would be about 1 inch per year.

The assumptions in the above calculations were conservative, and consequently the calculated value represents an overestimate. It may be concluded, therefore, that this particularly hazardous radioisotope is unlikely to become a significant ground water contaminant, at least insofar as its introduction into the environment as fallout from past weapons testing is concerned.

SUMMARY

Inorganic contamination of ground water, like organic chemical and biological contamination, is the price society is paying for exploiting this essential natural resource. In many instances, an isolated toxic effluent of industrial origin can be treated to remove a specific contaminant so that neither surface nor ground water pollution results. When the problem involves a large single source of highly saline water, there appear to be only two economically feasible alternatives: surface discharge with adequate dilution or subsurface disposal into deep formations well below the level of fresh water aquifers. In a particular river basin, if the volumes of dilution water are not adequate to ameliorate the salinity problems created by industry, deep injection is the only solution. A seaboard community or industry has the ocean of course, where inorganics should pose no problem.

Irrigated agriculture creates a much more difficult problem, since the many sources of inorganic contamination are dispersed and generally have natural access to gravity aquifers and surface streams. Here the solution must evolve from basin-wide optimization of water utilization so that the greatest benefit is derived per unit of consumption. In certain locales (e.g., the west side of the San Joaquin Valley) agricultural sewers may prove feasible and allow separation of highly saline return waters from still usable ground and surface waters. In other situations, if agriculture is to continue at its current level, interbasin solutions must be sought that may require the transportation of dilution waters over great distances.

REFERENCES

1. McKee, Jack E. Water Quality Criteria. California Water Pollution Control Board Publication 3. 1952. Also: Addendum No. 1, Water Quality Criteria. 1954.
2. U. S. Atomic Energy Commission. Standards for protection against radiation. Title 10, Part 20. Federal Register, November 17, 1960.
3. Jones, H. B. The Nature of Radioactive Fallout and Its Effects on Man. Hearings, Special Subcommittee on Radiation, Joint Committee on Atomic Energy, 85th Congress, 1st Session, Washington, D.C. 1957. Pp. 1100-1137.
4. Wilcox, L. V. Water quality requirements for irrigation. Proceedings, Conference on the California Ground Water Situation, Univ. of California, Berkeley, December 3-4, 1956.

5. Quality of Ground Waters in California, 1955-56. Bulletin 66. Department of Water Resources, State of California. 1958.

6. Survey of ground water contamination and waste disposal practices. Task Group Report. Jour. AWWA, 52:1211-1219. Sept. 1960.

7. Eaton, F. M. Factors to consider in salt balance studies. Proceedings, Conference on Quality of Water for Irrigation, Univ. of California, Davis, January 21-22, 1958.

8. Morse, R. R. The nature and significance of certain variations in composition of Los Angeles Basin ground water. Economic Geology, 38:475-511.

9. Love, S. K. Natural radioactivity of water. Ind. and Eng. Chem., 43:1541-1544. 1951.

10. Smith, B. M., Grune, W. N., Higgins, F.B., and Terrill, J.G. Natural radioactivity in ground water supplies in Maine and New Hampshire. Jour. AWWA, 53:75-88. 1961.

11. Straub, C.P., Setter, L.R., Goldin, A. S., and Hallbach, P. F. Strontium-90 in surface water in the United States. Jour. AWWA, 52:756-768. 1960.

12. Orcutt, R.G., Kaufman, W.J., and Klein, G. The Movement of Radiostrontium Through Natural Porous Media. Progress Report 2. Sanitary Engineering Research Laboratory, Univ. of Calif., Berkeley. November 1, 1956.

ORGANIC CHEMICAL CONTAMINATION OF GROUND WATER

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Approximately 12 million wells are in use in the United States. In Ohio, bounded by Lake Erie on the north and the Ohio River on the south and traversed by several rivers, more than 2 million of the 10 million people depend upon ground water for their water supply. These numbers are cited to emphasize the extensive use of ground water and the consequences of polluting our ground water resource.

A limited documentation of incidents of ground water contamination and of the development of interest in such problems is presented in the reports of the AWWA Task Group on Underground Waste Disposal and Control (1, 2, 3, 4). These are compilations of information supplied by State and Territorial Departments of Health, supplemented by that from other sources.

The 1952 report was an analysis of data received from 38 states and 2 territories. Only a few states recognized any problem due to contamination of ground water. Most of the reported incidents involved bacterial contamination by sewage, or chlorides from oil- or gas-field brines. Apparently only one state, Michigan, provided detailed information on such problems. That state reported four cases in which a specific organic contaminant was involved. In two of these, the contaminant was a phenolic compound; in the other two, gasoline.

The 1953 report was largely a policy statement. It noted that "although ground water pollution by industrial-waste disposal is reported as relatively minor in many states, and even non-existent in some, it is, nevertheless, nationwide in distribution." Specific organic chemical contaminants, not noted in the previous report, were picric acid and cleaning fluid.

The 1957 report is a compilation of information from the 1952, 1955, and 1957 questionnaires sent to the states, supplemented by data from a U. S. Geological Survey study made during 1955. Forty-two of the 47 states that reported are shown to have experienced problems with contamination of ground water.

The 1960 report summarizes information from a questionnaire specifically requesting data on incidents observed during 1957, 1958, and 1959, plus some supplemental information coming to the attention of the Task Group. During that 3-year period, 39 states reported one or more problems involving contamination of ground water.

Information presented in these two reports indicates that only three (Hawaii, Mississippi, and New Hampshire) of the 50 states have escaped problems resulting from the contamination of ground water. Table 1 summarizes the data by type of organic contaminant and shows the number of states that reported one or more incidents due to such contaminants. Incidents in which sewage, industrial wastes, or other nonspecific organic contaminants were detected are not included in this table. During the last 3 years, organic contaminants reported included detergents, gasoline, oil, other petroleum products, and petrochemicals (in order of number of states that reported contamination, see Table 1). The types of organic chemical contaminants reported to have been responsible for one or more incidents of ground water contamination are:

ABS
Creosols
2, 4-Dichlorophenoxy acetic acid
Dichlorophenol
Gasoline
Hexachlorocyclohexane
Hydrocarbons
Kerosene
Methane
Oil
Pentachlorophenol
Phenol
Phosphonates
Picoline
Picric acid
Pyridine
Trichloroethylene

Table 1. NUMBER OF STATES THAT REPORTED SPECIFIC TYPE OF ORGANIC CONTAMINATION OF GROUND WATER

Organic contaminants	To 1957(3)	1957-1959(4)
Gasoline	9	7
Oil and fuel oil	6	6
Other petroleum products	2	4
Detergents	3	8
Other petro chemicals	2 [a]	3
Phenolic compounds	1	1
All types	19	20

[a] Includes one case where picric acid was involved.

The increasing number of states reporting experiences with detergent contamination of ground water provides evidence of the growing interest and concern in organic chemical contaminants. Problems with detergent contamination were reported for three and eight states, respectively, in the 1947 and 1960 AWWA Task Group reports, but for 18 states in a more recent publication (5). Additional information now indicates that such problems have been encountered in at least 20 states.

The European literature contains numerous reports on contamination of ground water. A recent German publication (6) cites 60 cases in which ground waters had become contaminated with petroleum or petroleum products. Forty-five of these incidents were first detected within the last 10 years. Hettche (7, 8) has described an interesting incident in which a village near Hamburg, Germany, had a high morbidity of goiter associated with urochrome contamination of the ground water supply. Other articles report organic chemical contamination of ground waters from such sources as graveyards, sanitary land fills, and agricultural use of fertilizers and economic poisons.

Information from Europe indicates that the United States will probably experience an increasing number of such incidents, as density of both population and industry increase.

SANITARY ENGINEERING CENTER STUDIES

Interest in the removal of organic chemical contaminants from water percolating through pervious soils led to the installation of carbon adsorption units on several wells near contaminated surface waters. At Peoria the Illinois State Water Survey cooperated with the Center in a study of the effect that artificial recharge of Illinois River water has on the quality of the ground water. Carbon adsorption units were installed to sample waters from the river and from two wells, one 100 feet and the other 1300 feet from the recharge pit. The concentrations of chloroform and alcohol extractable materials and those of certain broad chemical groupings were measured. Table 2 presents the principal results. These data show that filtration through 100 feet of this aquifer did not appreciably reduce the organic substances present in the river water. The organic substances in the water from the well 1300 feet from the recharge pit were similar in character to those in the water from the river but substantially lower in concentration. It is not known whether the concentrations of these organic contaminants were reduced by passage through the aquifer or were diluted by water from other sources.

The water from a Clermont County well was also examined. This well was located approximately 150 feet from the bank of the Ohio River, some 20 miles upstream from Cincinnati. Analyses of samples obtained by the carbon adsorption method showed the organic content of this water was not characteristic of Ohio River water. The concentration of contaminants recovered from the well water was only one-sixth that obtained from the river water.

Also included in Table 2 are analyses of waters from an uncontaminated well in Texas and from a grossly contaminated well in Colorado. Water from a well at Gallipolis, Ohio, contained one-third the concentration of contaminants found in water from the Ohio River at Huntington, West Virginia. Huntington is 40 miles downstream from Gallipolis.

Data for water from a well some 300 feet from the Merrimack River, near Lowell, Massachusetts, are not shown. The gross contamination - 240 ppb carbon chloroform extract and 320 ppb carbon alcohol extract, plus the presence of oil - exceeded that in the river water. These data are mentioned only to emphasize the possibility of picking up such organics as lubricants for pumps, and cutting oils and jointing compounds from pipe connections.

How does one detect organic contamination of ground waters, and what are the best procedures for determining their composition and source? Synthetic detergents provide a builtin indicator; these compounds are reported to foam at concentrations as low as 0.5 ppm. The first evidence of the contaminant may be a housewife's observation of foam on water drawn from the tap. Taste and odor, however, are the most common indicators of contamination of ground waters by organic contaminants. Crop damage by ground water used for irrigation has, in at least one case, been the first indication of contamination; however, taste and odor also were reported. Lack of taste and odor is no assurance that water is not contaminated.

A few examples of the procedures used to identify the objectionable components, once contamination was recognized, will be related. When taste and odor occurred in water from a community well in Colorado, samples of the water were collected for ABS analysis and a carbon adsorption unit was installed on the system. The ABS analysis showed 0.65 ppm; the carbon adsorption unit yielded 433 and 892 ppb of chloroform and alcohol extractable materials, respectively. Clean well waters show less than 100 ppb of such extractables. Analyses of the chloroform extractable materials showed considerable concentrations of hydrocarbon materials and the presence of solvent-like compounds. In addition, an unidentified

Table 2. ORGANICS IN WELL AND SURFACE WATERS, AS MEASURED BY THE CARBON ADSORPTION METHOD

Source of sample	Sampling period	Approximate distance from river, ft	Chloroform extract, ppb	Alcohol extract, ppb	Total	ABS, ppm[a]
Clermont County well	3/3-3/21/58	150	25	25	104	--
Ohio River at Cincinnati	2/12-2/27/58	--	387	425	812	--
	3/12-3/24/58		207	250	457	--
Gallipolis, Ohio, well	7/21-8/26/58	500	45	174	219	--
Ohio River at Huntington, W. Va.	7/2-7/16/58	--	151	188	339	--
	8/1-8/18/58		92	177	268	--
Peoria, Illinois Illinois Water Survey (Well No. 19)	3/18-4/23/59	100	178	483	661	
	1/19/59					0.70
Company A Well No. 3	3/18-4/24/59	1300	85	183	268	
Well No. 5	1/19/59	1800				0.17
Illinois River	3/19-4/23/59	--	148	356	504	
	1/18-19/59[b]					0.70
Canutillo Well Field, El Paso, Texas	1/18-2/3/61	--	17	36	53	--
Town and Country Well, Commerce Town, Colo.	7/17-7/26/57	--	433	892	1325	0.65

[a] Measured on liquid samples.

[b] 24-hour composite.

plastic-like substance was obtained. This material dried to a tough film. Investigation showed that a waste lagoon receiving washings from a road tractor cleaning plant was a likely source of the contaminant. Another possibility was infiltration from a small stream receiving wastes from an airport and effluent from a sewage treatment plant. The strongest evidence for tracing contamination is the identification of a unique substance both in the ground water and in the suspected source of contamination. If the contaminating substances are not unique, the levels of contaminants in polluted wells can be compared with those of other wells in the area.

In another incident, taste and odor was the complaint; suspicion was strong that leakage of crude oil from storage tanks was the cause of the contamination. An investigation by use of the carbon adsorption technique showed that the well water was contaminated but that the materials were most likely from a surface or river source, since no evidence of oil contamination could be found. An alternative possibility is that ancient pollution from a nearby source finally became evident. In a third case, contaminants in several wells were traced directly to an industrial waste lagoon and the materials present could be obtained by direct distillation. A series of chemical examinations of these substances provided unequivocal evidence of the similarity of the compounds present.

OTHER EXPERIENCES

Numerous cases of taste and odor in water have been attributable to gasoline; a few ppb of gasoline will cause odor in water. Some unusual assays for gasoline have come to our attention. A story, reportedly true, is told of a man who lighted his morning cigarette after drawing a basin of water in preparation for shaving. Flame that occurred on the wash basin was traced to gasoline contamination. In another instance, a floating layer of liquid was removed from a water well. The investigators, suspecting gasoline, poured the liquid into a car; the car ran. Techniques for identification of minute concentrations of gasoline in water are somewhat weak; however, gas chromatographic methods that are expected to make possible, with reasonable effort, the detection of gasoline in water in low ppb concentrations are now available. A good chemist is the prime requisite for the successful measurement of minute amounts of organics.

Although our present information on the persistence of organic contaminants in ground waters is limited, indications are that once such materials reach the water table they may persist for long periods of time. ABS is difficult to degrade biologically and is expected to persist in ground waters. Evidence indicates also that compounds easily destroyed in surface waters may persist in ground waters.

A widely known case of persistent water contaminant occurred at Montebello, California (9, 10, 11). A chemical corporation in Alhambra, California, manufactured 2-4, D weed killer from 2,4-dichlorophenol, monochloroacetic acid, caustic soda, hydrochloric acid, diethanolamine, and acetone. A batch of the raw material was inadvertently discharged to the sewer. It passed through an activated-sludge sewage treatment plant and thence to the San Gabriel River. These materials traveled 3 miles above ground in the river and then seeped into the underground stream from which Montebello drew its supply. Although the industry operated for less than 1 month, the taste- and odor-producing substance, apparently unreacted 2,4-dichlorophenol, required special treatment of the waters for a period reported to have been from 4 to 5 years.

Another case showing long-time persistence of phenolic compounds in ground water has been reported by Flynn (12). An industry that commenced operation in 1946 discharged phenol-bearing wastes from cleanup operations into open pits excavated to a depth of about 4 feet into dry sand. Complaints of phenolic tastes in water from a 100-foot-deep well 1500 feet from the disposal pits were received in 1951. Analyses of the waste and well waters revealed the presence of 80 ppm and 20 to 40 ppb phenol, respectively. Apparently, in 5 years the phenolic compounds had seeped downward approximately 38 feet to the water table and then moved 1500 feet in the saturated aquifer to contaminate the well water.

Although the responsible industry ceased discharge of phenolic wastes to the ground in 1951, it was not until 1957, after more than a year of continuous pumping of the well water to waste, that phenols were no longer detectable. Table 3 shows the distances traveled by some organic contaminants in ground water.

A very unusual incident (13), in which the contaminants found in the water were not discharged as such but were, apparently, the reaction products of two or more wastes, deserves mention. Alkali and chlorine wastes were discharged to a pond, the reaction product, chlorates, appeared in the ground water, apparently after traveling several miles, causing crop damage and loss of use of the water. In the same incident, chlorine, phenolic compounds, and acetic acid in wastes discharged to a holding pond evidently reacted to form 2,4-D.

This emphasizes the need to consider the possibility that substances separately discharged into waste ponds may react to form products more toxic than those originally discharged.

Table 8. DISTANCES AND TIMES OF TRAVEL OF SOME ORGANIC CONTAMINANTS THROUGH VARIOUS GEOLOGICAL FORMATIONS

Contaminant	Geological formation	Distance of underground travel, ft	Apparent time of travel	Ref
ABS	?	4,000	14 mo	14
	Sand and gravel	1,000	?	
	?	700	6-7 mo	15,16
Gasoline	Fractured limestone	6,500 to 10,000	5 yr	17
	Sand and gravel	2,300	7 yr	18
	?	300	?	19
Oil	?	900	?	20
	Fractured stone	650	?	21
	?	880	?	22
Phenol	Sand and gravel	1,500	4-6 yr	18
Picric acid	?	15,000	4-6 yr	8

SUMMARY

A wide variety of organic contaminants are reaching ground waters from leaky tanks, lagoons, and septic tanks, or by accidental means. The problem is nationwide, and the reported incidents probably represent a small fraction of actual occurrences. The presence of contaminants has been evidenced by taste and odor, foaming, and crop damage. Once the contaminants have entered the ground water, they may travel for long distances and persist for years. Materials, such as phenol in compounds, that are ordinarily degraded easily in surface waters are not readily degraded in ground waters. The determination of the contaminants in ground water and the location of their source may be difficult. The detection of unique materials, if present and demonstrable, in the ground water and in the pollution source offers the best evidence of the source of contamination.

Knowledge of time of travel and geology, of biological and other effects, of saturated and unsaturated aquifers, and of soil types, as related to organic contamination of ground waters, is limited. Concerted effort is needed to extend this knowledge.

REFERENCES

1. Control of Ground Water Waste Disposal, Progress Report of AWWA Task Group E 4-C, JAWWA, 44: 625-689 (1952).
2. Findings and Recommendations on Underground Waste Disposal, Report of AWWA Task Group E 4-C, JAWWA, 45: 1295-1297 (1953).
3. Underground Waste Disposal and Control, Report of AWWA Task Group 2450R, JAWWA, 49: 1334-1342 (1957).
4. Survey of Ground Water Contamination and Waste Disposal Practices, Report of AWWA Task Group 2450R, JAWWA, 52: 1211-1219 (1960).
5. Walton, Graham. "Effects of Pollutants in Water Supplies - ABS Contamination," JAWWA 52: 1354-1362 (1960).
6. Michels, Na[illegible]ert, Udluft, and Zimmerman, Gutachten Zur Frage des Schutzes des Grundwassers gegen Verunreinigung durch Lagerflussigkeiten (Expert opinion on Questions of the Protection by Aquifers against Contamination of Ground Water), Bundesministerium fur Atomkernenergie and Wasserwirtschaft, Bad Godesberg (June, 1959).
7. Hettche, H. O. Urochromes in Water as the Cause of Endemic Goiter, Gas-und-Wasserbach 96, No. 20, 661-64 (October 15, 1955).
8. Hettche, H. O. Fundaments of a New Goiter Prophylaxis. Monatskurse fur die Arzliche Fortbildung No. 5 (May 15, 1955).
9. Derby, Ray. Symposium on Industrial Waste and Industrial Waste Water. ASTM Special Technical Publication 207 (195[illegible]).
10. Sayre, A., and Stringfield, V. Artificial Recharge of Ground Waste Reservoirs. Jour. AWWA 40: 1153 (1948).

11. Water Quality Criteria. Publication No. 3. State Water Pollution Control Board, Sacramento, Calif. (1953).

12. Flynn, John M. Private Communication.

13. Weintraub, Robert L. Rocky Mountain Arsenal Waste Status Report 25, (May, 1959).

14. Neel, J., and Hopkins, G. Experimental Lagooning of Raw Sewage. J. WTR Poln. Control Fed., 28: 1325 (1956).

15. Newell, I., and Almquist, F. Contamination of Ground Water by Synthetic Detergents. J. NEWWA, 74: 61 (1960).

16. Almquist, F. O. Private Communication.

17. Muller, J. Bedeutsame Feststellungen bei Grundwasserverunreinigungen durch Benzin. 93, 1952, 205 - 209; Abstr. JAWWA 45:(3):66P&R.

18. Fricke, K., and Krause - Wichmann. Starkere Grundwasserverunreinigungen durch Benzin bei Wesel. Gesundheitsing 74, 1953, 394 - 396; Abstr. JAWWA 48: (4) 64 P & R.

19. Cederstrom, D. J. The Arlington Gasoline - Contamination Problem. U.S. Dupl. Rept. 5 pp. (1947: Abstr. USGS Water Supply Paper 1492, p. 28.

20. Hogg, C. Petts, A. E. J., and Collett, W. F. Prevention of Pollution by Oil from Engineering Factories - Discussion by J. H. Spencer, Surveyor, London, 107:6 (1948); Abstr. WPA 24, No. 910.

21. Grober, Diskussionsbemerkung Gas. u. Wasserfach 96, 1955, 468.

22. Meinck, F. Beobachtungen und Betrachtungen zu einer Olverunreinigung des Untergrundes. Gesundheitsing. 18-20 (1958): Abstr. WPA 31, No. 443.

EXPERIENCES IN THE NETHERLANDS WITH CONTAMINATION OF GROUND WATERS

J. K. Baars, The Netherlands

In the Netherlands, ground water is one of the main sources of potable water. Not less than 94 percent of all the waterworks use ground water, and they supply 77 percent of the total water consumed; therefore, the problem of ground water pollution is of extreme importance in the "low lands," particularly in the Western part of Holland where the waterworks are situated in dunes areas. The water is collected from aeolian deposits of very fine sand, 90 percent between 0.30 and 0.15 mm in diameter. In other parts of the country the sand is coarser (85% between 0.42 and 0.15 mm) but still of good filtering quality.

Population growth in the last decade has resulted in greater water consumption, and several large waterworks have increased their capacity by artificial production of ground water. The transformation of surface water of average quality into ground water of high quality has been studied extensively in the last 10 years, including the purifying capacity of these sandy soils. This may be illustrated by consideration of artificial ground water infiltration for the town of Leyden.

The catchment area of the Leyden waterworks is situated just south of Katwijk. Here the ground water is collected partly by drains located above an impervious clay layer 5 meters below surface level, and partly from wells that penetrate much deeper layers. There is a limit to this source, however, since underneath the dunes the brackish water seeps into the polders, thus limiting the fresh water reservoir formed by rain water.

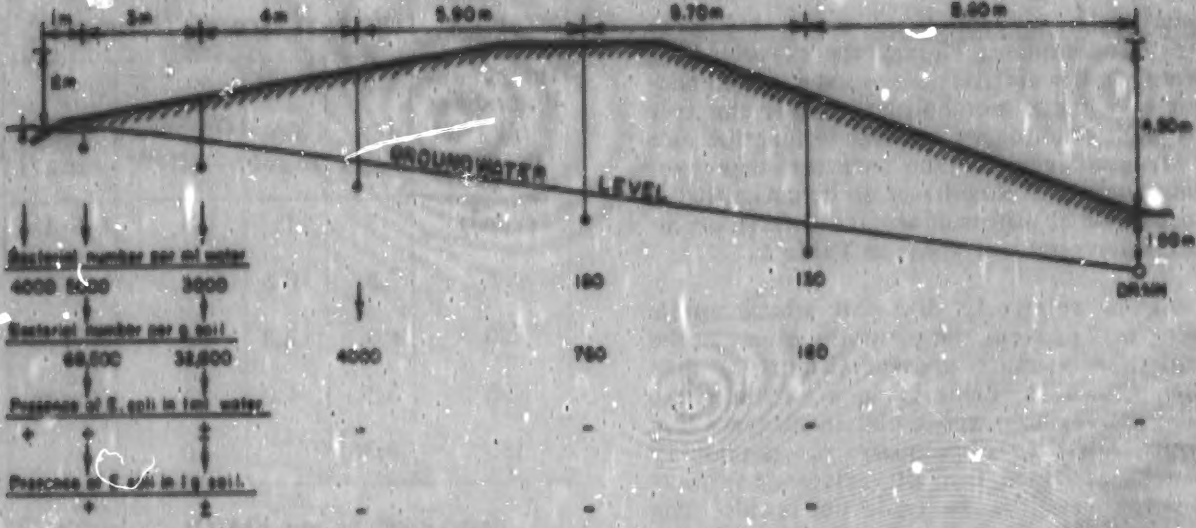
1m
3m
4m
5.90m
5.70m
5.90m
5m
4.50m
1.50m
GROUNDWATER LEVEL
DRAIN
Bacterial number per ml water
4000 5000 3000 180 130
Bacterial number per g soil
68,500 38,800 4000 760 160
Presence of E. coli in 1ml water
+ + ± - - - -
Presence of E. coli in 1 g soil
+ ± - - -

FIGURE 1. INFILTRATION THROUGH BODY OF SAND (GRAIN SIZE 0.15mm) — 6 MONTHS IN OPERATION

Since 1940 in this dune area surface water has been brought into infiltration ponds where its quality improves markedly during percolation. The E. coli content of the water as it penetrates from the ponds into the soil is about 100 to 200 per ml, whereas the total number of bacteria varies between 1000 and 5000 per ml (counted on nutrient agar after 48 hours incubation at 37° C). After the water has filtered through the dune sand, E. coli is absent in 100 ml and the total number of bacteria is less than 100 per ml.

Bacteriological analysis of the sand around such infiltration ponds gives good insight into the filtering capacity of the soil (Figure 1). The water content of 1 gram of sand is approximately 0.2 ml. The bacterial count in the sand-water mixture is about 70,000 per gram, much more than can be present in the water alone. Most probably the bacteria are adsorbed on the sand grains (which may be an electrophysical process), or even are simply filtered off; it is known that particles may be kept back in capillaries with a diameter many times greater than the particles considered. The same decrease in bacteria is found in a vertical direction from the bottom of these infiltration ponds (Figure 2).

In this decrease in the bacterial number may be seen the struggle for life of the bacterial flora of the subsurface layers. With increasing depth, too, the ratio of spore-forming to nonspore-forming bacteria increases from 1.3 to 10 to 15 percent. B.

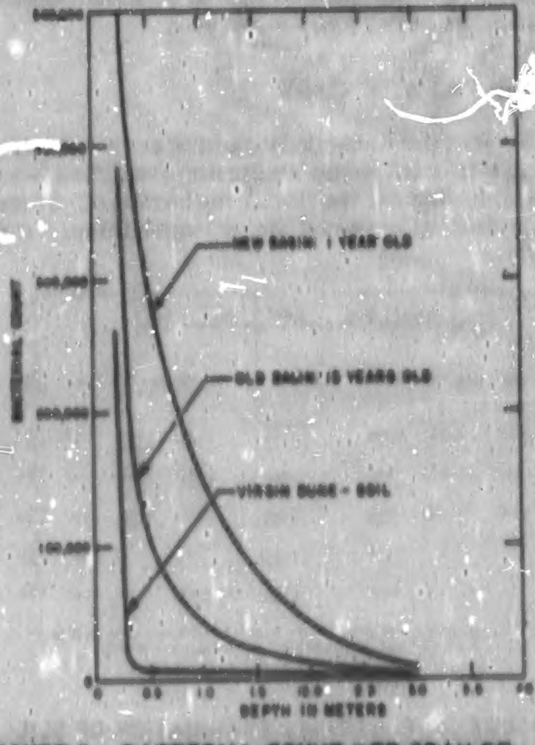

FIGURE 2. BACTERIAL COUNT PER GRAM OF SOIL AT INCREASING DEPTH UNDER BOTTOM OF INFILTRATION BASIN

subtilis, B. mesentericus, and B. mycoides are predominant. During the travel of the water in the soil, oxygen is used by the bacteria in their metabolism. After the free oxygen is no longer present to function as a hydrogen acceptor, the nitrates take over this function. Results of an investigation of test wells at different distances from an infiltration pond are given in Table 1.

In a relatively dry soil where ample oxygen is present, the purifying effect in the soil may be much greater (Figure 3) than that shown in Table 1. In a tourist camp near Hilversum, where the inhabitants live from April to September in temporary shacks provided with pit privies, the purification results are quite noticeable. The essential factor in this situation is an abundant supply of free oxygen in the soil.

If there is a lack of oxidizing capacity, the bacteria may stay alive much longer and the nitrogen compounds will be only partly transformed into nitrates. The presence of nitrates is an indication that mineralization has been only partly achieved.

THE KATWIJK CASE

Near the Katwijk catchment area a camping site with some sanitation facilities was established by the local authorities. Since the facilities were quite insufficient, the

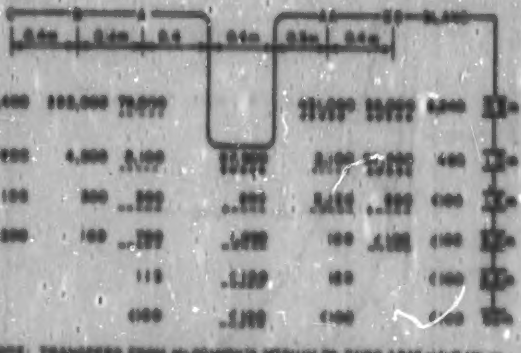

FIGURE 3. BACTERIAL EXAMINATION OF SOIL 7 MONTHS AFTER END OF CAMPING SEASON—BACTERIAL DENSITY AND RESULTS OF McCONKEY FERMENTATION TEST

Table 1. PURIFICATION IN DUNE SOIL

Horizontal distance of well from pond, m	O_2, mg/l	NO_3, mg/l	Organic matter[a]	NH_4, mg/l
(Pond)	5	11	55	0.5-1.0
5	7.5	10.5	45	0.1
30	4.0	7.3	28	Trace
55	5.5	4.0	24	Trace
155	0.36[b]		18	

[a] Expressed as mg $KMnO_4$ consumption per liter.

[b] Mixing with surface water possible.

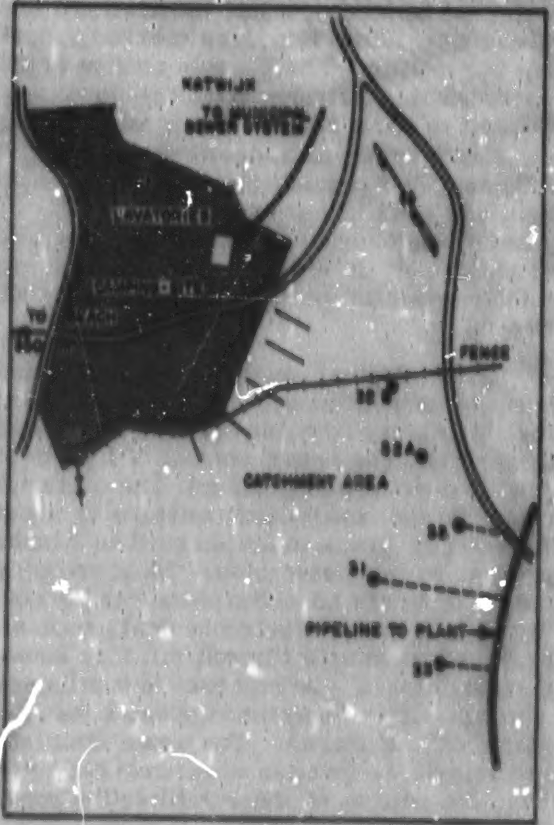

FIGURE 4. POLLUTION OF GROUND WATER AT KATWIJK (LEIDEN WATERWORKS)

sewage that should have been pumped away into the Katwijk sewer system undoubtedly must have passed the emergency overflow weir and penetrated into the subsoil.

In August 1960 the water of the wells had a slightly greater bacterial count, so the frequency of chemical and bacteriological analyses was increased. The bacteriological quality of the water was not significantly worse, but the chemical analysis showed serious pollution (Table 2). The presence of nitrites is considered proof that strong pollution with ammonia or proteid ammonia has occurred and oxidation has only partly transformed these components into nitrates. It is known that, in contrast with the ammonia salts that are adsorbed on the sand particles, the nitrates and nitrites can pass freely, so detection of nitrates at a few hundred meters is not surprising.

To obtain a further insight into this case of ground water pollution, two additional wells were constructed, 32A at half the distance from well 32, and 32B adjacent to the borderline of the camp. In these waters again nitrites were found (Figure 4).

The fluctuations in the nitrogen content are considered proof of the transportation of the more or less mineralized polluting substances. This point is mentioned because it is known that, for instance, water from peaty soil may contain more nitrogen components than other natural water, but then the peat water shows the same composition over a long period of time.

The expectation that, in this fine-grained sand, bacterial pollution would not be detected in wells 31, 32, and 33 was confirmed. Despite a nitrate content of 14.6 mg/l, the bacterial count per ml of water was no more than 4.

THE VELUWE CASE

The sudden and simultaneous occurrence of three cases of tuberculosis in one family living in the neighborhood of a sanatorium led to a thorough examination of the individual water supply of two bungalows and a cottage in a rural district in the central part (Veluwe) of the Netherlands. At the start of the investigation, each of the houses was equipped with an individual water supply from a drilled well 10 meters deep. The subsurface of the region consists mainly of coarse sands and gravels dating from Middle Pleistocene times.

During the penultimate glacial period (the Saale period) some of these deposits were thrust up by the ice front into the "push

Table 2. POLLUTION OF GROUND WATER AT KATWIJK (LEIDEN WATERWORKS)

Chemical analysis, mg/l[a]

Well	7/27/60	11/3/60	11/26/60	12/19/60	12/27/60		1/10/61		1/31/61		2/7/61		2/20/61		3/20/61	
Number	NO_3	NO_3	NO_3	NO_3	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	McCumkey test (10-ml samples)	Bacteria per ml
31			< 2		< 2	0							< 2	0.6	Negative	10
32	23.5	34	42	16.6	18.0	0	6.2	0	14.2	0	34.5	[illegible]	14.6	0	Negative	4
32 A				Trace	< 2	0	5.0	4.5	5.8	3.7	6.2	3.0	4.4	5.2		
32 B				6.9	7.0	0	10.5	6.9	16.8	9.2	17.7	2.0	16.6	6.6		
33			< 2	Trace									< 2	0	Negative	6

[a] All samples contained about 0.2 mg NH_3 and 0.5 mg proteid NH_3 per liter

moraines" of the Eastern Veluwe. Loam lenses have been found locally, possibly dating from the Neede period, the warm interglacial period proceeding the Saale glacial period.

The greater part of the region is covered by a thin layer of so-called cover sand, and aeolian sand deposited during the last glacial period.

In general it may be said that impermeable layers are absent. Figure 5 gives a schematic view of the situation. The waste water from the sanatorium was sterilized only by abundant use of phenolic disinfectants and then allowed to settle in a septic tank, the overflow water being disposed of to a small open canal serving as a feeder for an underground drainage system in cultivated fields.

An inspection of the waste disposal system of the sanatorium revealed that surface seepage of black phenolic waste had occurred in a pine forest outside the fields. The gradients of the fields are about 1 : 100. It seems reasonable to expect clogging of the drainage system to develop nearest to the sanatorium and the inlet in the feeder canal.

Table 8. QUALITY OF SURFACE WATER AND GROUND WATER IN THE NEIGHBORHOOD OF SANATORIUM (VELUWE)

CHEMICAL ANALYSIS	Spring of rivulet	Rivulet 300 m from spring	Well W 1 (depth 10 m)	Well W 2 (depth 10 m)	Well W 3 (depth 20 m)
Permanganate number ($KMnO_4$), ppm	17	8	8	3,5	1,8
Chloride, mg/l	80	15	70	10	11
Nitrite, mg/l		Trace	1,1	0	0
Nitrate, mg/l		Trace	110	Trace	Trace
Sulphate, mg/l		11	18	11	5
Bicarbonate, mg/l		38	31	87	26
Carbon dioxide, mg/l			20	7	7
Ammonia, mg/l		1,0	7,0	0,1	Trace
Total hardness ($CaCO_3$), ppm	36	30	80	33	28
Phenols, mg/l	800	50	60	100	35
BACTERIOLOGICAL ANALYSIS	(Number of samples)				
Eykman Fermentation Test	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]
50 ml	3 0	1 1	2 0	2 0	2 0
10 ml	1 1	0 2	2 0	[illegible] 0	2 0
1 ml	3 0	0 0	2 0	2 0	2 0
Completed Coli Test	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]
50 ml	1 1	0 2	5 0	5 0	5 0
10 ml	5 0	3 2	2 0	5 0	2 0
Colony Counts at 37°C					
24-hr incubation at 22°C (2 mos)	0 0	5 3	0 0	0 0	0 0

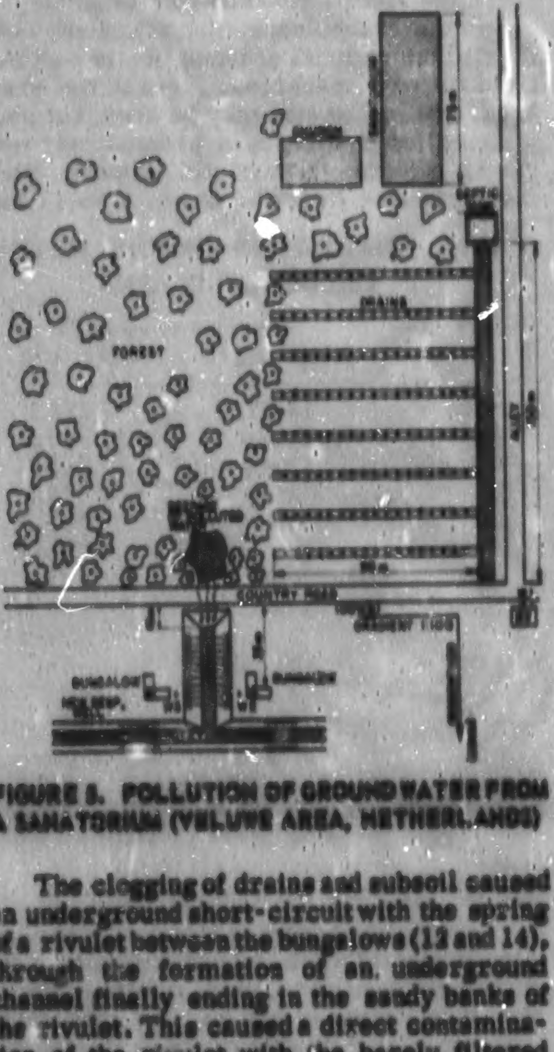

FIGURE 3. POLLUTION OF GROUNDWATER FROM A SANATORIUM (VELUWE AREA, NETHERLANDS)

The clogging of drains and subsoil caused an underground short-circuit with the spring of a rivulet between the bungalows (12 and 14), through the formation of an underground channel finally ending in the sandy banks of the rivulet. This caused a direct contamination of the rivulet with the barely filtered waste water of the sanatorium. The waters of the three individual wells (W 1, W 2, and W 3) and of the rivulet were examined.

The chemical and bacteriological results are summarized in Table 3. Although the search for pathogenic organisms yielded negative results, chemical analysis of the well water of W 3 showed a strong biochemical transformation of organic substances into ammonia and nitrates; all the samples contained various amounts of phenolic substances.

The waters of wells W 1 and W 2, near the bungalow (14) where the outbreak of tuberculosis occurred, were still found to be almost pure chemically, except for the phenolic components already mentioned.

Owing to the inhibitory effect of the phenolic substances, the bacteriological examinations showed a complete absence of normal pure water bacteria. In the water of the rivulet near the spring, and even more at a distance of some hundred meters from the spring, fecal contamination easily could be detected by the presence of B. coli, in spite of the phenolic substances.

The viability of pathogenic organisms enfeebled by toxic substances is an unknown and unsafe factor.

Sanitation of the water supplies of the houses was effected by elimination of the underground infiltration of the waste water from the sanatorium in the neighboring field, together with an improvement in the purification of the waste water and the establishment of a water supply for the houses from a deep communal well. At a depth of 50 meters the ground water proved to be completely free from any traces of chemical or bacteriological contamination.

OTHER CASES

At another camping site (Oostvoorne) the ground water level is only 1 meter below the surface. Until 6 years ago contamination of the subsoil was frequent, and 8 out of 12 samples of ground water taken from private wells showed the presence of B. coli. These wells were only 5 to 8 meters deep. The results of chemical and bacteriological analyses are given in Table 4.

The sanitary condition at Oostvoorne camp has since been improved considerably; measures have been taken to dispose of fecal matter in a proper way, and drinking water is obtained from a central distribution system (which is true of 90% of all Dutch communities).

At a small town in Gelderland, which had no central water supply, the ground water very often was polluted locally by fecal matter to such an extent that the content of nitrogen components was considerable. This may

Table 4. CHEMICAL AND BACTERIOLOGICAL ANALYSES [a] OF WATER IN WELLS AT OOSTVOORNE CAMP

Well number	NO_2, mg/l	NO_3, mg/l	NH_4, mg/l	E. coli
2	0,12	6,0	0,24	+
5	0,50	7,3	0,11	-
6	Trace	0	0,45	+
7	0,04	11	1,8	+
8	0,10	6,8	0,87	-
9	0,03	50	0,26	+
11	0,04	20	0,10	+
14	0	28	0,07	-
19	0,12	22	2,7	+
20	0,38	81	0,03	-
21	Trace	4,5	0,07	+
	0,22	86	1,4	+

[a] The preliminary isolation was made in glutamic acid medium; the Imvic test was used for final confirmation.

have consequences with regard to methemoglobinemia. The results of analyses of the ground water at 10 farms (A, B, C, D, E, F, G, H, K, L) in the Gelderland area are given in Table 5.

At the time of sampling, reasonably good water was available only at farms F and K. The safety of even these water supplies, however, is to be considered very doubtful!

In the last 10 years oil drilling has begun in the Netherlands, and now about one-third of the national consumption is supplied from its own resources. Even in the dunes area, drilling towers may be seen, but permission for drilling was granted only with rather severe restrictions. Among other measures that had to be taken, it was compulsory to outfit the drilling plant completely with a concrete floor with curbing to prevent any leakage of waste, either oil or brine, into the underground.

Table 5. ANALYSES OF GROUND WATER IN GELDERLAND AREA

Farm	NH_4, mg/l	NO_3, mg/l
A	13.05	228.1
B	Trace	16.5
C	Trace	148.4
D	Trace	19.5
E	8.4	157.2
F	0	Trace
G	0	132.9
H	Trace	88.6
K	2	Trace
L	Trace	69.9

SUMMARY

Although the purifying capacity of the soil may be considerable under favorable conditions, the load of polluting substances may sometimes surpass this capacity. The first signs of serious pollution of ground water are detected by chemical analysis, whereas in a later phase bacterial pollution of the ground water may be found. In the latter event the water is generally oxygen free, and it is to be expected that bacterial pollution may remain present for a very long period.

DISCUSSION 2

Chairman: W. E. Gilbertson

Dr. Jack McKee asked Dr. W. M. Mallmann whether he has any information on the travel of enzymes through soil. Dr. Mallmann answered that he has no information on this subject but he would anticipate that enzymes might travel in the same manner as viruses; he added that information on the travel of viruses in the soil is very limited.

Mr. George F. Hanson of the University of Wisconsin asked whether there is any limit to the distance water-borne organisms may travel in fractured limestone formations. Dr. Mallman replied that there is no practical limit on the distance these organisms might travel through the solution channels that commonly occur in limestone formations.

Mr. Ralph Baker of the Florida State Board of Health asked Dr. Mallman's opinion on the need for differential testing of coliform bacteria on samples taken for sanitary analysis. Dr. Mallman stated that time did not permit the long discussion that such a question might require but that in general he would not recommend such differentiation (the IMViC test, which is used to differentiate between fecal and nonfecal coliform bacteria).

Mr. Norman Tuckett of the Broward County Health Department (Fort Lauderdale, Florida) asked Mr. F. M. Middleton for elaboration on the effects that drainage from sanitary landfills has on contamination of ground water. The question was referred to Dr. C. Walton, who stated that considerable evidence has been cited in connection with sanitary landfills but that he did not have specific instances at his fingertips. He added that perhaps this subject could be explored further following Mr. Leo Weaver's presentation on refuse disposal.

Mr. Herbert Swensen of the Geological Survey asked Mr. Middleton whether phenolic materials were likely to be discharged by sugar beet processing plants; he believed this had been reported. Mr. Middleton said he knew of no phenolic problems connected with sugar beet processing.

Mr. George Maxey of the Illinois State Geological Survey asked Mr. Middleton how organic contaminants disseminate in ground water. It was stated that little information is available on travel of organic pollutants. Mr. Barry Andres of C. W. Lauman & Co., Inc., was asked to relate some of his experiences in tracing detergent pollution on Long Island. Mr. Andres said he and his co-workers had followed ABS for 1000 feet and that a path 100 to 300 feet wide was detected. The ABS was found at depths as great as 100 feet below the top of the aquifers (see paper by John M. Flynn).

Mr. Ralph M. Soule of the Massachusetts Department of Public Health then related an experience with contamination of wells by phenols and manganese and gave an account of the extreme difficulties encountered when an attempt was made to alleviate the pollution by a variety of methods. Interceptor wells were installed between the pollution source and the contaminated well. Pumping these wells reduced the contamination only slightly. The contaminated well water then was pumped and spray aerated to oxidize the contaminants. Although the phenolics and manganeses were reduced, this treatment did not produce satisfactory water.

Mr. Martin Dretel of Brewster, New York, asked Dr. J. K. Baars what he believes is a safe nitrate concentration in water. Dr. Baars indicated he did not wish to make a firm statement but that he thought up to 100 ppm would not cause trouble, although the World Health Organization standards are only 50 ppm NO_3 (12 ppm NO_3-N). In connection with the nitrate problem, Norman Biegler of the Kansas State Board of Health stated that a study in Kansas indicated that nitrates were concentrated near the water table and that simply extending the casing of a low-capacity well frequently resulted in a water with a much lower nitrate content.

SESSION 3

SPECIFIC INCIDENTS OF CONTAMINANTS IN GROUND WATER

Chairman: R. E. Fuhrman

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Problems Arising From Ground Water Contamination by Sewage Lagoons at Tieton, Washington, R. H. Bogan . . . . . . Page 83

Infectious Hepatitis Outbreak in Posen, Michigan, J. E. Vogt . . . . . Page 87

Ground Water Contamination in the Greensburg Oil Field, Kentucky, R. A. Krieger . . . . Page 91

Incidents of Chromium Contamination of Ground Water in Michigan, Morris Deutsch . . . . Page 98

Refuse Disposal -- Its Significance, L. Weaver . . . . Page 104

Underground Natural Gas Storage (Herscher Dome), O.S. Hallden . . Page 110

Two Cases of Organic Pollution of Ground Waters, R. H. Burttschell, A. A. Rosen, and F. M. Middleton . . . . Page 115

Contamination by Processed Petroleum Products, L. M. Miller . . . Page 117

The Movement of Saline Ground Water in the Vicinity of Derby, Colorado, L. R. Petri . . . . Page 119

Public Health Aspects of the Contamination of Ground Water in the Vicinity of Derby, Colorado, G. Walton . . . Page 121

Discussion . . . . Page 125

GROUND WATER CONTAMINATION IN THE MINNEAPOLIS AND ST. PAUL SUBURBS

L. Woodward, Minnesota Department of Health

During the last 2 years a great deal of publicity has been given to the disclosure that the ground water in the suburbs of Minneapolis and St. Paul has been extensively contaminated by sewage, affecting the individual household wells serving a relatively large population in the area. Much of the publicity has been critical of the interpretation of the findings and of the fact that some alarm has resulted. Significantly, this criticism has come largely from persons and organizations with an economic interest in the continued development of on-site water supplies, i.e., home builders, well drillers, and persons furnishing well equipment and water-conditioning equipment.

Several factors, which in combination may be unique to this area, have contributed to the situation. By the end of 1959, some 400,000 persons in the suburbs were dependent upon individual water supplies or individual sewage disposal systems or both. Perhaps the most important single factor was the lack of control of platting. In the suburbs there were no local health services other than those provided by a part-time health officer, and there was no authority for a State agency to exercise control over development of subdivisions. Ground water is readily available throughout most of the area, at depths of 20 to 70 feet, so that a developer could justify individual wells instead of community water systems that would involve him in operation of a utility. Also, soil conditions are generally favorable for the absorption of liquids. In the early postwar years most of the developers were small operators who did not have the resources to install community sewer systems, particularly in view of a lack of convenient and suitable outlets. Minneapolis and St. Paul, although willing to contract with adjoining suburbs within the limits of the capacity of their respective sewage collection systems, were unable, in general, to furnish relief beyond the first ring of suburbs, and many of these applied for service only after a high population density had demonstrated the failure of on-site facilities.

Another factor that solved some problems but did little to provide regulation of housing development was a rash of municipal incorporations (see Figure 1), which totaled 35 in the Twin City area between 1950 and 1960. Fifteen of these made villages of entire townships or of the parts of townships remaining after smaller villages had been created. The purpose of the latter type of incorporation was to prevent further erosion of territory by development of villages within the township or selective annexation to other municipalities, which eventually destroy the tax base for maintenance of township services. Most of these new communities came into being without ordinances and without experience in municipal government.

How the Situation Developed

Soon after the rather slow start of postwar building the Minnesota Department of Health issued several warnings, by direct communication and through the press, calling attention to the inevitable result of using the same soil formation for sewage disposal and for water supply in areas of substantial housing developments. These warnings were largely disregarded. The developers did not care to assume the legal responsibilities of arranging for maintenance and operation of central facilities, and local governments, except well-established municipalities, were reluctant to embark in the utility field to provide service to many scattered developments in a large semirural area. Furthermore, the State Department of Health and the

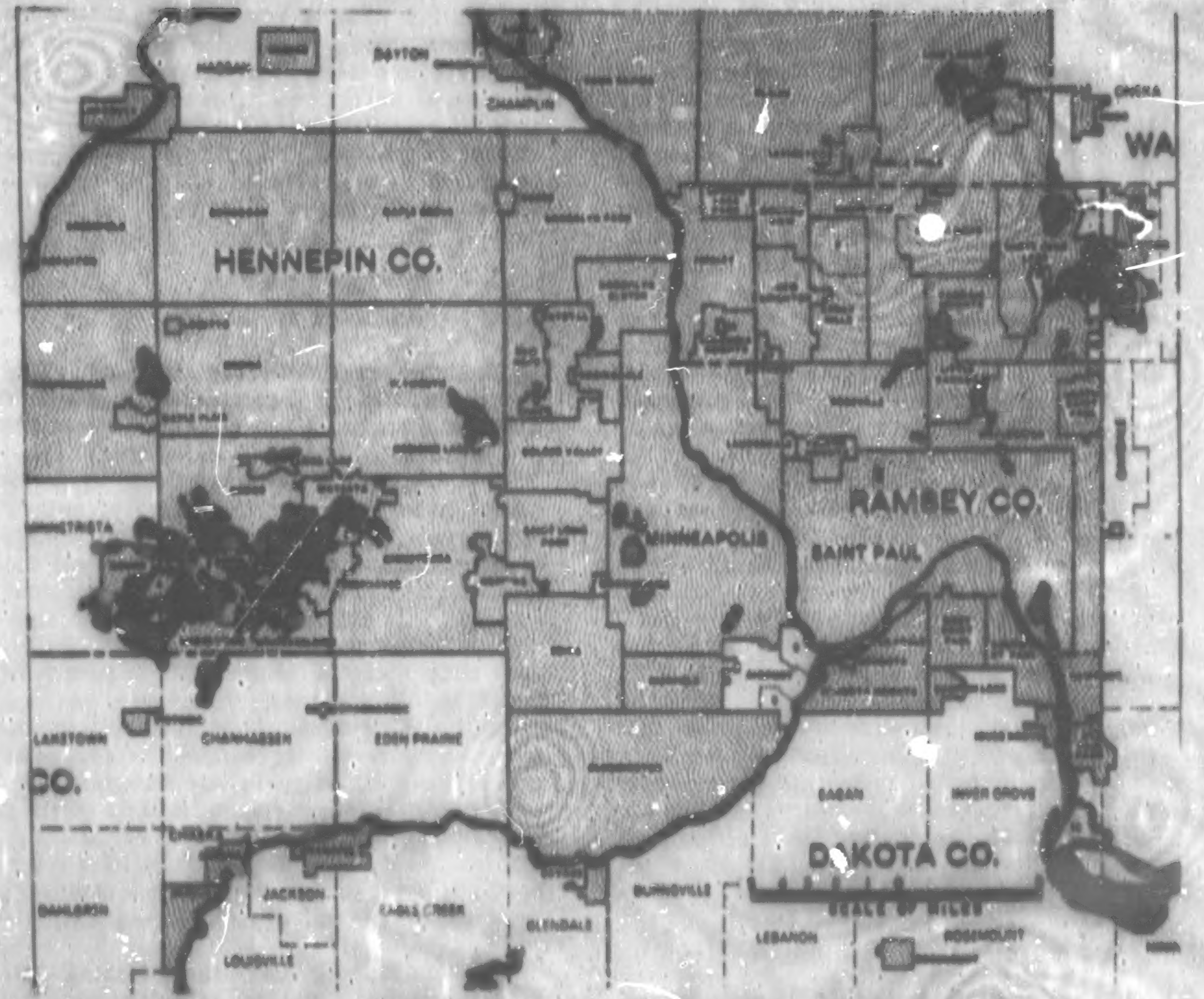
DAYTON
CHAMPLIN
HASSAN
ANOKA
WA
HENNEPIN CO.
RAMSEY CO.
MINNEAPOLIS
SAINT PAUL
MINNETRISTA
LAKETOWN
CHANHASSEN
EDEN PRAIRIE
CO.
EAGAN
INVER GROVE
DAKOTA CO.
SCALE OF MILES
DAHLGREN
JACKSON
EAGLE CREEK
LOUISVILLE
GLENDALE
BURNSVILLE
LEBANON
ROSEMOUNT

FIGURE 1. MINNEAPOLIS–ST. PAUL AND SUBURBS – SHADED AREAS ARE INCORPORATED MUNICIPALITIES

Water Pollution Control Commission could not look favorably upon any proposal to discharge sewage into any of the very small or intermittent streams that would be the only economical outlet for sewage in many of the isolated developments. For the latter reason the construction of central water supplies was urged, with individual septic tank systems to be accepted for sewage disposal until proper central collection and disposal could be economically justified.

The first privately owned water system installed after World War II was constructed in another state in 1946 by a developer of a half dozen custom built homes. This developer incorporated his water supply to meet the FHA requirement of guaranteed perpetuity of service. Since that time many large developers have installed central water systems where their immediate building plan has made such systems economically attractive. FHA later adopted a policy requiring central water systems in developments coming under their approval, if the feasibility factor did not exceed approximately 1.5.

In 1956 a serious occurrence of ground water contamination in an unincorporated area north of St. Paul was caused by the discharge of surface water and septic tank effluents from a housing development of several hundred homes into the underlying limestone formation. In the area studied, the surface of the limestone varied from 18 to 36 feet below the ground surface and most of the septic tanks discharged into leaching pits up to 18 feet in depth. The use of drainage wells for disposal of surface water had been common in the township. Sampling of about 150 wells showed that a significant number of these were contaminated bacteriologically. The only chemical examination made was for hardness, and this test showed extensive effects of the softer surface water on the hardness of the well water. (Like most other public health agencies the Minnesota Department of Health long ago abandoned the sanitary chemical examination of drinking water in favor of the more easily interpreted bacteriological tests.) The inclusion of nitrate and surfactant tests in this study probably would have yielded information that would have been more convincing than the bacteriological findings, especially since the residents were not aware of any illness that they believed had been caused by water. An election to authorize a township water supply was defeated, but the developer installed a central water system for a part of the area and the City of White Bear Lake annexed other parts and furnished water to them from the municipal system.

In April 1959 a housewife in a seworless suburb north of Minneapolis telephoned to report unexplained illness in her family, coupled with a peculiar taste and appearance of her well water. She was especially concerned with the persistent foamy film on the surface of the water after it was drawn from a tap. Remembering reports of the finding of synthetic detergents in ground water in other parts of the country, and especially on Long Island, the State Health Department decided that this situation should be studied. Accordingly, samples of the well water were examined quantitatively for surfactant, nitrate nitrogen, and coliforms. The surfactant level was found to be 1.1 ppm and the nitrate nitrogen level, 11 ppm. No coliforms were found. The water from a neighbor's well contained 0.91 ppm surfactant, 7.6 ppm nitrate nitrogen, and no coliforms. Since both wells were about 30 feet deep and were located and constructed in general accordance with accepted standards, it was decided to attempt additional studies in the area. The village council was receptive to the proposal and assisted in a survey of the entire community of 10,000 people.

Survey Procedure and Findings

Samples were collected at random from a statistically representative number of wells and analyzed for nitrate, surfactant, and chloride. Chloride was included in this survey because it was believed that the rather general use of exchange-type water softeners might make this a valuable tracer of sewage movement; however, because of the lack of correlation with the other chemical findings, this analysis was not made in subsequent surveys. Nitrate nitrogen in significant concentrations from 1 to 21 ppm was found in 62.2 percent of the supplies examined; 10.2 percent contained 10 ppm or more. Surfactants were found in 23.6 percent of the samples, and there was good correlation between the concentrations of surfactants and the concentration of nitrates. Coliform tests of water from the 10 percent of the wells showing the highest chemical evidence of contamination were negative.

The publicity given to these findings, by the community involved, resulted in immediate requests for similar surveys throughout the area. By the end of January 1961, 40 such surveys were completed and comprehensive reports furnished to the community officials. Generally, these surveys covered an entire village or township; however, a few were carried out in a single housing development. In five communities all wells tested were affected, and in one small annex of about 100 homes all results were negative. The composite results, representing over 63,000 wells serving more than 250,000 people, showed that about 46-1/2 percent of the wells were contaminated, as evidenced by the presence of nitrate or surfactants of sewage origin. Nitrate nitrogen in excess of 10 ppm was found in 10.6 percent of the wells tested, and measurable quantities of surfactant were found in 21.8 percent of the wells. The concentration of sewage chemicals in the water has varied in individual cases from a trace to an amount sufficient to indicate complete or multiple recirculation of sewage.

Factors Affecting Contamination

In younger (postwar) communities 10 to 20 percent of the wells most seriously affected by sewage chemicals are also contaminated bacteriologically, as evidenced by coliform organisms in the water, whereas in older communities as many as 50 percent of all wells are so affected. Other than age of a community factors that have been found to affect the occurrence of ground water contamination are: well depth, character of soil, population, and rate and direction of ground water movement. Tables 1 and 2 show the relationship of well depth and age of community to concentration of nitrate in areas with similar soil characteristics.

Table 1. RESULTS OF STUDY OF WELLS IN TYPICAL POSTWAR COMMUNITY

Well depth, ft	Number of wells	% of waters with >1 ppm NO_3-N
0 - 25	8	50
26 - 50	18	28
51 - 75	8	37
76 - 100	13	8
101 - 125	0	
126 - 150	1	0
151 - 175	1	0
176 - 200	2	0

Table 2. RESULTS OF STUDY OF WELLS IN TYPICAL OLDER COMMUNITY

Well depth, ft	Number of wells	% of waters with >1 ppm NO_3-N
0 - 50	6	67
51 - 75	10	50
76 - 100	21	71
101 - 125	5	100
126 - 150	3	67
151 - 175	1	0

The influence of soil characteristics on contamination travel varies considerably. In some communities wells that penetrate several layers of clay have been affected. In others, including one with no affected wells, clay soil has appeared to be the factor that has furnished protection. Various conclusions may be drawn from this. Most logical, perhaps, is the conclusion contamination is less likely to occur in areas where the clay layers are continuous and undisrupted over extensive areas than in areas where only islands of clay exist or where the clay has failed to settle around some of the well casings. In areas where limestone aquifers are near the surface of the ground, all wells generally are affected with sewage chemicals and bacterial contamination is common.

Geology of Area

In the Twin City area the earth formation consists of alternate layers of shales, limestones, and sandstones of varying thickness, showing the various effects of glaciation and erosion. The overlying drift varies in depth from zero to over 200 feet, and its character ranges from tight clay to sand, gravel and, in some cases, boulders resulting from the breaking and erosion of the rock formations. About half of the wells included in the current studies terminate in the drift, and the remainder in limestone or sandstone.

Most of the wells affected in the 1956 episode were developed in the shallow Platteville limestone that underlies that particular area. The five communities in the current studies, where all wells tested were contaminated, are underlain by the Shakopee-Oneota dolomite. In both instances sewage from individual systems can move readily into and through the rock formation. The development of safe wells in such situations requires grouted construction through the faulty limestone and into the St. Peter sandstone in the area of the 1956 episode, and into the Jordan sandstone in the area of the wells currently being studied.

Municipal and commercial wells in the area generally terminate in the Jordan sandstone, which is the principal high-yield aquifer, or in deeper formations. Often the Shakopee-Oneota dolomite has been used where it is protected by sufficient cover and sufficient distance from an outcrop. Continued draft has brought about a deterioration of quality in some of these wells, and more rigid construction and operation requirements have been imposed.

Basis for Determining Contamination

The use of 1 or more ppm nitrate nitrogen as evidence of sewage contamination is based on the fact that nitrate does not commonly occur in more than trace amounts in ground water in the Twin City area. This is supported by the findings of the surveys - over half of the well waters tested contain less than 1 ppm nitrate nitrogen. Critics have pointed out that other states and the Public Health Service have suggested limits of 10 to 20 ppm for assessing the safety hazard of nitrate nitrogen in drinking water and that for this reason the standard of 1 ppm is unrealistic. These people choose to disregard the fact that this standard is not used as a measure of toxicity but as an indicator of sewage contamination. They state that a limit of 10 ppm or even 5 ppm would be more realistic and acceptable. They apparently do not question the use of surfactant as a criterion, although they have suggested that in low concentrations it has no health significance. For several years the Minnesota Department of Health has recommended against the use of water that contains more than 10 ppm of nitrate nitrogen for infant feeding, and in each of the surveys in this study the owners of wells showing this level of nitrate have been given individual warnings.

In Table 3 the overall survey results are arranged to show the percentage of wells that would be considered as showing evidence of contamination with various combinations of nitrate and surfactant.

Table 3. PERCENT OF WELLS CONTAINING NITRATE NITROGEN AND/OR SURFACTANT

Contamination criterion	% of wells
Over 1 ppm NO_3-N	41.2
5 ppm NO_3-N	25.1
10 ppm NO_3-N	10.6
Surfactant	21.8
Over 1 ppm NO_3-N or surfactant	46.5
Over 5 ppm NO_3-N or surfactant	33.6
Over 10 ppm NO_3-N or surfactant	24.0

Policy of Federal Housing Administration

Although the FHA is concerned with much less than half of the home loans in the area, its policies are adopted directly by the Veterans Administration and, in addition, they influence the policies of conventional lending agencies. Consequently, FHA interest in the quality of ground water has economic impact on the entire home building industry. On February 3, 1960, the Director of the Minneapolis office of the FHA issued a circular letter establishing limits of 1 ppm nitrate nitrogen and 0.2 ppm surfactant for individual water supplies of homes to be considered for FHA mortgage insurance. The policy is not retroactive but does apply to all new guarantees and to the refinancing of existing properties. It can be modified in individual instances where there is assurance that a safe supply of water will be available within a limited and definite time. The issuance of this policy evoked loud criticism from the building industry, but it has remained in effect, with the full support of higher echelons of FHA. The pattern of home building has changed, with more builders installing central water supplies and with deeper, more expensive, individual wells being needed where central systems are not feasible. Builders who are able to advertise that their development has city water have taken full advantage of the opportunity.

Results

Since the summer of 1959, ten communities have completed, or started construction of, municipal water supplies that will serve 150,000 people, based on the 1960 census. In addition, other communities have extended their systems to areas not previously served and eight private water companies have been established to serve particular housing developments in areas not served by municipal systems. Elections to provide public supplies have failed in eight villages, but new elections have been successful in two of these.

In April 1959 St. Louis Park, with a 1960 population of 43,310, established its first full-time health service. Later, Bloomington 50,500, Richfield, 42,523, and Edina, 28,500, established similar services. The full-time services provided are principally those of a sanitarian, and the latter three communities established their services as a direct result of the water supply situation.

In addition to the great interest in public water supplies, much concern has been expressed about the conservation of the quality of both the shallow ground water and the water in the deeper formations by the installation of sewers in areas now served by septic tanks and soil absorption systems. The Legislature is considering several bills that would permit the creation of sanitary districts wherever necessary for the solution of problems involving multiple jurisdictions. The most important and necessary proposed legislation in this field would provide an expanded metropolitan sanitary authority that would include most of the suburbs in a joint district with the Twin Cities at a cost of about $100 million. Other bills related to the solution of this problem would require licensing of well drillers, installers of septic tank systems, and scavengers.

Serious thought is also being given to the ultimate needs for water in the area. The limit of productivity of the Jordan sandstone may soon be reached, and the likelihood that more reliance must be placed on the Mississippi River as a source is recognized. The capacity of the river is also limited, with the peak demands of Minneapolis and St. Paul approaching half of the minimum flow. Consideration is being given to various methods of augmenting low water flows, to supply the needs for domestic and industrial use and for dilution of sewage effluents. The most likely possibility appears to be regulation of the navigation reservoirs on the headwaters of the Mississippi River; however, diversion of water from the St. Croix River and a 150-mile conduit from Lake Superior also are being considered.

IMPACT OF SUBURBAN GROWTH ON GROUND WATER QUALITY IN SUFFOLK COUNTY, NEW YORK

J. M. Flynn, Suffolk County Health Department

Suffolk County, the east end of Long Island, is bounded on the north by the Long Island Sound and on the south by bays created by parallel barrier beaches between the bays and the Atlantic Ocean. The 10 townships of the County comprise 922 square miles and had a population in 1960 of 665,550, or 723 persons per square mile. From 1950 to 1960 the population increased approximately 390,000 persons, or 60 percent. The most startling growth was in the urban population, which increased 298 percent. The four western townships, about one-third of the total area, contain approximately 71 percent of the population, or nearly 1600 persons per square mile. In addition, the growth of the western towns still exceeds that of the eastern towns. The water resources of Suffolk County are estimated to be sufficient to support a population of 3.5 million.

Planning and regulation to insure orderly development of Suffolk County, as they affect water supply and waste disposal, are largely the responsibilities of town building departments and planning boards and the Suffolk County Health Department. In those areas under realty subdivision regulations, there has been an opportunity to review plans for water supply and sewage disposal for each subdivision. The development of public water supplies for most of these subdivisions has proceeded in an orderly fashion; however, sewage disposal has been almost exclusively by individual subsurface leaching systems.

The greatest difficulty has been encountered with water supply and waste disposal in areas where development by various builders was carried out piecemeal on sites selected from old filed maps. These areas unfortunately are not subjected to planning and health regulations as realty subdivisions are.

GEOLOGY AND HYDROLOGY

The topography of Suffolk, like that of most of Long Island, slopes gently from the north to the south shore. The only abrupt topography is along the north shore where elevations may change several hundred feet over distances of 500 feet. The terrain of the County was created largely by glacial action; two glacial moraines transverse the Island from northwest to southeast. Natural drainage is by streams and lakes, most of which are small and run off to either Sound or Bay. Long Island is underlain by bed rock, which dips at a rate of about 80 feet per mile from northwest to southeast and from north to south. This rock is encountered at depths of about 400 feet on the north shore and 2000 feet on the barrier beaches.

The Island was formed during several geological periods. In the first period Applachian runoff deposited a coarse sand that forms the basis of the Lloyd stratum directly above the bed rock. The nature and velocity of the runoff varied, resulting in the deposition of Raritan clays upon the Lloyd sands. Further changes in the runoff resulted in the formation of the Magothy, the thickest stratum, which is a mixture of sands, clays, and gravels. As indicated by occasional lignite and other coal formations, the Magothy stratum was originally near sea level and was swampy.

Erosion appears to have been the predominant force later, with Long Island Sound having been formed by a stream flowing eastward. During the Pleistocene era, which followed, glaciers covered portions of Long Island. These glaciers deposited large quantities of sands, gravels, and clays on the north portion of the Island at the termination of the moraine.

The final era, marked by the end of the Ice Age, carried large quantities of sands and gravels to the south of the glacial moraine. The finer materials were deposited off shore where they formed the muds and clays in the bay bottoms. A period of erosion resulted in the formation of the barrier beaches that parallel the south shore. The glacial outwash covers most of central and south Suffolk and is characterized by medium to coarse sands and gravels extending to depths of 100 feet.

At a rate of approximately 500,000,000 gallons per day, ground water is recharged naturally by rain, snow, and sleet, and artificially by storm drainage, cooling water, and domestic sewage. Rainfall alone accounts for approximately 800,000 gallons per square mile per day. The annual rainfall is 42 inches, of which about 50 percent finds its way into the ground water. In the central portion of the Island the water table is approximately 70 to 80 feet above sea level. Because of this elevation differential, the fresh water, moving at 0.5 to 2.0 feet per day, discharges naturally at the north and south shores. An artificial discharge is created by withdrawals of water for public water supply and for industrial or agricultural use. Portions of this water are discharged to the sea as treated or untreated sewage and as storm drainage.

A safe yield from the ground waters is that at which the present water table is maintained; withdrawal exceeding that amount would lower the water table below sea level and result in salt water intrusion. Such intrusion of salt water has occurred where withdrawals have exceeded the safe yield. Temporary salt intrusion also has occurred in wells close to shores where the sealing muds and clays in bay and harbor bottoms have been removed by dredging.

The three most important water-bearing strata in Suffolk County are the Glacial, Magothy, and Lloyd. The Glacial is the upper and most productive stratum. The Magothy is the thickest formation and contains many good water-bearing strata. The Lloyd stratum is productive but extremely deep, and since recharge is slow, it is generally reserved for use when the Glacial or Magothy fail to produce water or are unavailable.

PUBLIC WATER SUPPLY

Approximately 59 percent of the population of Suffolk County obtain water from 90 communal or public supply systems. The largest supplier is the Suffolk County Water Authority, which serves various locations throughout the length of the County. Other suppliers include town districts, incorporated villages, private companies, and community or civic associations.

In Table 1 the estimated numbers of people served by public water supply and private wells as of January 1960 are listed for each town.

The present trend is toward the construction and extension of public water supply systems to serve the vast areas of the County that still employ individual wells. This problem is especially crucial in the four western townships where plot densities, as many as seven per acre, and population densities are extremely high. The trend toward installation of public water supply facilities in the east end also is growing. In many rural areas, however, private wells on large plots still may be used with some safety.

Table 1. SUMMARY OF WATER SUPPLY AND POPULATION FOR 1960

Town	Total population	Public Water Supply Number of services	 Estimated population served	Private Wells Number of wells	 Estimated population served
Babylon	142,909	22,007	77,500	19,200	64,800
Islip	172,960	23,720	101,300	21,000	72,560
Huntington	126,221	29,901	104,000	6,250	22,221
Smithtown	50,347	7,779	27,200	6,600	23,140
Brookhaven	108,960	13,060	46,500	16,200	62,400
Riverhead	14,517	1,870	6,540	2,270	7,974
Southold	12,295	1,066	4,728	2,150	7,572
Southampton	26,861	2,400	18,900	2,266	7,961
East Hampton	8,887	2,000	7,000	880	1,887
Shelter Island	1,312	138	640	250	672
Totals	666,130	118,302	[illegible]	77,663	271,763

More than 85 percent of the Suffolk County water supplies is obtained from the Glacial stratum. Most of the remainder of these supplies is obtained from the Magothy stratum; a relatively small percentage is taken from the Lloyd stratum. The practice of obtaining most of the supply from the Glacial stratum has resulted in increased use of polluted water.

The Glacial stratum consists primarily of coarse sands and gravels, and it is into this upper stratum that wastes are discharged. The coarseness of the sands permits ready percolation and travel of wastes through this stratum. It is attractive as a source of water supply because productive wells can be obtained at depths of 50 to 100 feet and large quantities of water can be pumped from any single well. Although the Magothy stratum is deeper, requiring wells of depths from 300 to 700 feet, its yields often are equivalent to those of the Glacial stratum. The Magothy sands are overlain by lenses of clay and other impervious materials. Consequently, water reaching this stratum has had the advantages of long periods of storage and farther travel through finer filtering media, which are presumed to have certain ion-exchange or adsorption properties. The Lloyd stratum, the deepest source, is relatively untapped in Suffolk County. The policy of the Water Resources

Commission is to grant permission to use this supply only when all other sources are relatively unattainable in the specific area.

No evidence to date indicates that the Magothy stratum has been contaminated by wastes introduced into the ground waters; however, no evidence indicates that pollution of the Magothy is not possible. The determination of which stratum is used for water supply requires long-range planning, utilizing the knowledge of the geologist, well driller, and sanitary engineer.

The hazards of using water that is subjected to contamination are affected to a large degree by the amount of treatment given the supply before it is pumped into the distribution system. Where the quality of the raw source is unknown or variable, treatment substantially reduces the risk to the user. Treatment by the various water suppliers of Suffolk County is relatively limited; only about 10 percent of the water receives some chlorination. The amount of chlorination varies from 0.1 ppm to an occasional use of 0.5 ppm to offset seasonal complaints relative to iron and sulphur bacteria. In addition to chlorination some 30 percent of the suppliers adjust pH for corrosion control. Thus, the over-all treatment of water in Suffolk County is limited and the amount of disinfection provided is practically negligible. Much of the reason for this is the good bacteriological quality of the raw water and the general acceptance of the Long Island sand and gravel strata as infallible filtration barriers.

PRIVATE WATER SUPPLY

Approximately 41 percent of the present population in Suffolk County obtain water from some 77,800 individual domestic wells, as indicated in Table 1. The source of these well waters is almost entirely in the Glacial stratum. Many of these wells, particularly those in the western portion of the County, are located on small plots of 4000 to 7500 square feet, and the sewage disposal systems for these homes are located on these same plots. Contamination is inevitable, and the fact that it has occurred and is continuing to occur is constantly indicated by the unsatisfactory bacteriological and chemical analyses of such waters.

The degree of treatment accorded to these private well waters is practically negligible. A few home owners employ devices to feed phosphates into the water to control red-water problems. No practical, economically feasible devices are available for disinfection of individual well waters. Even if such were available, the program required to determine the effectiveness of 77,000 individual miniature treatment facilities would be enormous.

The questionable quality of the waters from these individual wells has been demonstrated. A limited knowledge of this situation is provided by those analyses that are performed by private laboratories for individual home owners at their own cost. The Health Department does sample private wells when requested by the family physician and also has made spot surveys of water quality in several areas where private wells are used.

SOURCES OF CONTAMINATION

To evaluate the extent of contamination from the various sources, it is necessary to rely upon over-all assumptions based on spot check investigations. More than 600 industrial plants are located in Suffolk County. Engineers from the Suffolk County Health Department have visited approximately 400 of these industrial plants. The studies show that at the time of survey 30 of the plants were discharging treated or untreated wastes.

In an intensive survey of the Town of Babylon, 350 industrial establishments in 26 separate areas were investigated. Industrial wastes were being discharged by 11 of the industries. Two additional industries were producing wastes in amounts of no significance, but they require continued observation for any change that may result in an increase in the wastes. Of the 11 industries, only two of the larger ones were treating their wastes. The combined wastes from 11 industries amounted to a total waste discharge of 17,[illegible]00 gallons per day. The materials discharged included the following contaminants: nitric acid, hexavalent chromium, cadmium, nickle, cyanide, and synthetic detergents.

To evaluate the pollution potential of laundry wastes, the Suffolk County Health Department instituted a survey of all laundry installations. Every known launderette and laundry was visited, and data relative to their operation were recorded. In general, data were sought on the number and capacity of machines, type and amount of washing compound used, amount of water used, and the type of sewage disposal system. A summary of the data is given in Table 2.

Table 2. SUMMARY OF LAUNDRY SURVEY DATA

Township	Number of laundries	Number of machines	Synthetic detergents, lb/mo	Soap, lb/mo	Water used, gal/mo	
					Private	Public
Babylon	34	384	[illegible]	3,100	804,800	387,750
Brookhaven	34	414	[illegible]	1,030	869,750	800,000
E. Hampton	1	19	--	--	110,000	--
Huntington	6	130	960	--	--	800,000
Islip	34	340	[illegible]	[illegible]	1,067,000	813,000
Riverhead	5	130	1,000	[illegible]	--	140,750
Smithtown	6	64	1,000	800	75,000	137,806
Southold	6	90	1,800	--	[illegible]	102,140
Southampton	5	96	3,475	300	337,000	370,337
Totals	100	1,552	[illegible]	[illegible]	[illegible]	[illegible]

Estimates based on the survey of laundrettes indicate that 1552 machines use 109,573,856 gallons of water and 436,578 pounds of detergent per year. The latter sum, however, does not include any detergent supplied by the launderette customer. The survey showed 78 launderettes disposed of wastes through subsurface leaching systems; seven, by collection in watertight tanks and hauling of the wastes to a disposal site; eleven, by discharge to public sewers; and two, by discharge to streams.

Approximately 95 percent of the domestic and sanitary sewage in Suffolk County is discharged through subsurface leaching systems into the ground waters. Only about 5 percent of the County's population use public sewers; consequently, substantial ground water contamination occurs. The daily discharges from the three principal sources of sanitary sewage are estimated to be (1) more than 2,000,000 gallons from large institutions and industrial plants, (2) 25,000,000 gallons from 150,000 private homes - this does not include the substantial increase in summer discharges that result from summer residents, and (3) 20,000 to 40,000 gallons from each of an unknown number of shopping centers and business areas.

Scavenger disposal sites are another source of ground water contamination. There are approximately 18 such sites to which the contents of cesspool cleaning trucks and other liquid wastes from business and commercial establishments are hauled.

A detailed survey of the cesspool cleanings from Babylon and Islip indicates that these towns produce 9,500,000 and 14,400,000 gallons per year, respectively. The volume of scavenger wastes is not recorded for the remaining eight townships; however, estimates place it at 16,000,000 gallons per year. The total for the County would exceed 100,000 gallons per day, and with the continued construction and subsequent failures of private sewage disposal systems, this amount is increasing constantly.

Unevaluated sources of ground water contamination are the 19 garbage disposal sites throughout the County. An estimate based on the County's present population places the quantity of garbage accumulated each year at 450,000 tons. A small part of this is incinerated; the remainder is incorporated in raw form into landfill. Undoubtedly, the decomposition of vast quantities of organic material is affecting the ground water in each vicinity.

The storm water recharge basins now in use or proposed for construction number over 400. These basins receive the portion of the rainfall that travels over the land surface and a large portion of the rainfall that accumulates on impervious areas such as roads, sidewalks, and parking lots. The daily discharge from the existing basins is estimated to be 10,000,000 gallons. The value of the recharge basins from the standpoints of both water conservation and disposal of storm water is unquestioned. The water discharged into these basins carries from the drainage area accumulative quantities of herbicides, insecticides, and road surfacing materials. No intimation is intended for adoption of controls or proposals to treat the contents of these recharge basins; however, the advisability of locating public water supply wells downstream from such basins must be considered. No serious attempt to evaluate the quality of the ground water downstream from recently constructed recharge basins has ever been made.

The large quantities of fertilizers and sprays used in the agricultural areas in eastern Suffolk County are an obvious but unevaluated source of pollution.

EVIDENCES OF CONTAMINATION

By the time the Department becomes aware of ground water contamination in any particular area, it usually is gross enough to result in complaints by users, relative to taste, odor, and other physical qualities. The investigation of such contamination usually results from complaints and in most instances is confined to the area of such complaints. Sixteen domestic wells and seven industrial wells in Islip and Babylon are known to have been contaminated by plating wastes consisting of hexavalent chromium, cadmium, zinc, or synthetic detergents, in varying amounts. The contamination of these 23 wells was determined by spot sampling downstream from known industrial waste discharges. This number does not represent all wells that may have been contaminated. The details of this survey are contained in a report by the Suffolk County Department of Health entitled "Survey of Industrial Wastes Town of Babylon," dated February 1958.

Contamination by laundry and launderette wastes of 25 domestic and 3 industrial wells has been evidenced by complaints and spot sampling throughout the County. A detailed study of the effect of launderette waste on the ground waters downstream from disposal facilities for such wastes was completed under a New York State Water Pollution Control Board research grant and is published as Research Report No. 5.

Contamination of over 1000 domestic and 5 municipal well fields by synthetic detergents has been substantiated by spot sampling initiated as a result of complaints by home owners. A Suffolk County Health Department report entitled "Study of Synthetic Detergents in Ground Water" contains the details of an intensive survey in one area.

Numerous chemical analyses of ground waters from domestic water wells have shown the presence of chemical constituents associated with decomposing organic substances. The amounts present sometimes have been consistent with those normally associated with ground water. More often such analyses have indicated the presence of these constituents in gross amounts, clearly indicating a close association with sewage discharges. Bacteriological examinations of waters from domestic wells have shown the presence of coliform organisms in amounts from an MPN of 2.2 to more than 2400 per one hundred milliliters. The coliforms found in these domestic wells are assumed to be the direct result of domestic sewage discharge into the ground waters from cesspools and seepage fields.

ABS PROBLEM

An ionic surfactant is the contaminant that appears with greatest frequency in Suffolk County. This surfactant, usually akhyl benzene sulfonate (ABS), is introduced as part of common products used in household laundrying and cleaning. Sampling, as a result of complaints, has indicated that ABS is present in more than 1000 of the domestic well waters that have been tested. Surveys in 13 area have shown the presence of ABS in as few as 8 percent of the wells in some areas and in as many as 95 percent in other areas. Because of limitations of manpower and laboratory facilities, not all wells in the areas studied were sampled; spot sampling has been necessary in all of the surveys conducted. The results of some of these surveys are presented in Table 3.

The ABS occurrence in private wells in Suffolk County is given in Table 4.

Contamination by ABS most frequently occurs in the densely populated and fast-growing southwest area of the County -

Table 3. SUMMARY OF PORTION OF ABS SURVEY IN SUFFOLK COUNTY

	Area	Number of wells sampled	Wells with ABS	% of wells with ABS
Amityville Harbor	1	81	27	33
Copiague	2	138	69	50
Lindenhurst	3	45	5	11
No. Lindenhurst	4	54	41	76
Babylon	5	20	19	95
West Islip	6	16	12	75
West Islip	7	100	29	29
West Islip	8	46	11	24
Islip	9	47	8	17
Fire Island [a]	10	34	2	6
Center Moriches	11	65	19	29
Mastic	12	18	7	39
Shirley	13	61	20	32.8

[a] Not a typical area, since it includes Cherry Grove, a summer colony; however, of 44 wells sampled, 26 showed coliform organisms (MPN ranged from 2.2 to 2,400).

Babylon, Islip, and Brookhaven. The ease of obtaining water from the Glacial outwash with its pervious sands and high water table has made installation of private wells in the southwest area inexpensive and easy. Although Huntington and Smithtown are also heavily populated and growing fast, the more impervious soils and greater depths to water have discouraged installation of private wells and public water supplies predominate.

The synthetic detergent problem becomes more severe with the passage of time. The ABS apparently is slow in polluting a well, but once a breakthrough is accomplished, the ABS content of the water increases rapidly.

In the North Lindenhurst area a survey carried out by the Department in October 1958 showed that 41 of 54 wells sampled con-

Table 4. ABS OCCURRENCE BY TOWNSHIP IN SUFFOLK COUNTY

October 1959-March 1961	Number of wells	Wells with ABS		ABS concentration, ppm			
		Number	%	0.05-0.4	0.4-0.9	0.9-1.4	>1.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75	51
Islip	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible]
Huntington	7	1	14.3	1	0	0	0
Smithtown	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0
Brookhaven	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	[illegible]
Riverhead	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0
Southold	4	1	25.0	1	0	[illegible]	0
Southampton	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0
East Hampton	[illegible]	0	0	0	0	0	0
Shelter Island	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0
Totals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

were collected from 34 of the 41 wells that had contained ABS in 1958. Two had the same ABS content as before, and two had decreased in content; however, 30 had increased in ABS content, and of the 30, the contents of 10 had doubled and that of 6 had tripled. The 1958 survey showed general ABS concentrations from 0.5 to 1.5 ppm, with two samples containing more than 1.5 ppm. The range for the 1959 survey was 0.5 to 4.5 ppm, with 13 containing more than 1.5 ppm and 7 more than 2 ppm.

ABS has been detected in waters from at least five well fields serving Suffolk County public water supply systems. All of the wells are shallow Glacial wells. The amounts of ABS in these wells have varied from 0.3 to 1.2 ppm, but to date no complaints have been received from consumers, probably because these amounts are below taste or foaming levels.

Those public supplies in which syndets have appeared are located principally in the heavily populated southwestern portion of the County. The well fields and methods of obtaining water in each of these areas are similar. Three of the fields each contain from five to eight wells spaced 75 to 100 feet apart and 50 to 80 feet in depth; all are pumped through common suction lines. Static ground water levels are high, varying from only 2 to 8 feet below grade.

ABS has appeared in each of these wells.

concentration varied from 0.1 to 0.9 ppm in the well water, with one having 5 times the concentration of an adjacent well. Increased pumpage of a well field has resulted in an increase in ABS content; and decreased pumpage, in a decrease in ABS content. All three well fields are large plots, varying from 4 to 8 acres, with ample protective distances around each well. Although all the wells have at least a 200-foot radius of protective area, all the fields are surrounded by heavily populated residential areas. Sewage is disposed of in all of these areas by individual subsurface leaching facilities.

The other two well fields in which ABS has been observed each contain a single well pumped by a deep-well turbine pump. Their depths are approximately 80 feet, and each well has a protective radius of 200 feet. The static water levels are relatively shallow, varying from 4 to 10 feet below the ground surface. The ABS contents in these wells have varied from 0.2 to 0.6 ppm. In one of these well fields the nearest sources of pollution are cesspools in a residential area approximately 1000 feet north of the well field. The intervening distance is occupied by a recreational area with no sewage discharges.

The presence of ABS in the shallow Glacial wells in southwestern Suffolk is readily predictable. Tens of thousands of homes in this area use subsurface leaching systems that discharge directly into the pervious Glacial stratum. It is believed that continued use of individual subsurface disposal systems will steadily increase the syndet content of water from the Glacial stratum until it is no longer acceptable.

Pertinent information on the behavior of ABS in ground water was contributed by the New York State Water Pollution Control Board Research Report No. 6, "Effect of Launderette Wastes on Ground Water." The hamlet of Mastic in which the water supplies for a number of residential homes have been polluted by ABS from a launderette was selected as a study area. Test

directions and to different depths. The horizontal spread of the syndet band was found to be at least 100 feet but less than 300 feet. The over-all length of the pollution slug was approximately 110 feet. This does not necessarily mean that the slug stopped at this point; a geological situation had produced conditions that made it inadvisable to attempt to follow the slug farther.

The vertical distribution of the pollution was limited by an impervious layer of clay approximately 100 feet below the surface. If this clay layer had not been present, the material undoubtedly would have continued downward. The downward travel was caused by additions of percolating rainfall and the greater specific gravity of the polluted water compared with that of less-mineralized natural ground water. The concentration of the material pumped from the test wells was reduced by biochemical degradation, dilution by ground and meteoric waters, and dispersion by travel through materials of varying transmissibility. Some of the ABS material pumped from test wells had been in the ground water 1 to 3 years with little or no degradation of the material. The age of this material has been based primarily on two factors: (1) the launderette had been closed for 1 year prior to the survey, and (2) for the 2 years prior to closing, the launderette had been using a detergent containing only nonionic surfactants.

The immediate effects of the discharge of launderette wastes into ground water was determined from test wells drilled at the site of a newly opened launderette in Deer Park. The disposal system for the launderette consisted of a septic tank, a distributing pool, and four subsurface leaching pools. To localize the point of entry of the waste, the four leaching wells were sealed off, with the result that the distributing pool received and dispersed all wastes. Test wells were located in groups along the anticipated path of ground water travel. Wells extending to various depths were included in each group so that vertical distribution and concentration of the effluent could be determined. The wells were pumped at various intervals, and their waters were analyzed for ABS. To

ABS and a tracer, common table salt. The ABS pollution from the launderette followed the general direction of the ground water flow, and the downward gradient of the pollution was similar to that observed in the Mastic study. Comparison of introduced and recovered chloride and ABS concentrations indicates no degradation of ABS under test conditions. The average chloride recovery was 14.2 percent, and that for ABS 16.1 percent. This is significant in that chlorides are not reduced by biochemical degradation. Since there was a comparable recovery of both chloride and ABS, little biochemical degradation of the surfactant can be assumed. Its reduction must be considered in terms of other factors, such as dilution by either dispersion or simple mixing and adsorption of the materials on the surfaces of clay and sand.

In August 1958 it became evident to the Suffolk County Health Department that the quality of the waters from private wells was poor and rapidly deteriorating. The need for corrective measures was obvious, and steps were taken. Townships and municipal suppliers were asked to cooperate in programs leading to the extension of public water supplies to serve existing residential areas. As a basis for approval, new subdivisions were required to provide public water supplies. Private wells were permitted only on plots with a minimum area of 20,000 square feet and where test wells demonstrated that waters of good quality were available on the realty subdivision site. When public water supply was demonstrated as economically impractical, private wells were permitted if they met new construction standards and if bacteriological and chemical analyses of each well were satisfactory. New standards required 100-foot separation between well and sewage disposal facilities. A minimum well depth of 50 feet, with the well drilled at least 40 feet below the water table, also was required. When the 100-foot distance was unattainable, however, the distance could be reduced to a minimum of 65 feet, provided that for every 5 feet of horizontal decrease there was a 2-foot increase in the vertical depth below the water table.

The first group of wells meeting these requirements were constructed in August and September 1958. Sampling of these wells indicated that each was satisfactory at the time of approval. In February and March 1961, approximately 2-1/2 years later, samples were collected from 47 of these wells to determine the quality of the water. The results are given in Tables 5 and 6.

Table 5 shows the relationship of well depth to concentrations of ABS, nitrate-nitrogen, and free ammonia-nitrogen. Table 6 shows the relationship of the distance between well and sewage disposal facilities to concentrations of ABS, nitrate-nitrogen, and free ammonia-nitrogen. Fifty-one percent of the wells sampled showed the presence of ABS. None of these well waters contained ABS at the time of their approval in the fall of 1958. The concentrations of ABS are low with a tendency for larger amounts to appear in shallower wells. Once the surfactant be-

Table 5. RELATIONSHIP BETWEEN WELL DEPTH AND CONTAMINATION

Well depth, ft	Number of wells	Wells with ABS	ABS, ppm 0.02-0.4	ABS, ppm 0.4-0.9	ABS, ppm 0.9-1.4	NO_3-N, ppm <1.0	NO_3-N, ppm 1.0-5.0	NO_3-N, ppm 5.0-10.0	NO_3-N, ppm >10.0	Free ammonia-nitrogen, ppm <0.5	Free ammonia-nitrogen, ppm 0.5-1.0	Free ammonia-nitrogen, ppm 5.0-10.0
50-55	4	3	3	0	0	1	2	1	0	4	0	0
55-60	1	1	1	0	0	1	0	0	0	1	0	0
60-65	11	5	2	2	1	8	2	0	1	8	3	0
65-70	7	3	2	1	0	3	2	2	0	6	0	1
70-75	23	11	11	0	0	10	5	4	4	22	1	0
75-80	1	1	1	0	0	0	1	0	0	1	0	0

Table 6. RELATIONSHIP BETWEEN WELL DISTANCE FROM CESSPOOL AND CONTAMINATION

Cesspool distance, ft	Number of wells	Wells with ABS	ABS, ppm			NO_3-N, ppm				Free ammonia-nitrogen, ppm		
			0.08-0.4	0.4-0.9	0.9-1.4	<1.0	1.0-5.0	5.0-10.0	>10.0	<0.5	0.5-1.0	5.0-10.0
65-75	16	9	6	2	1	9	6	1	0	12	3	1
75-85	1	0	0	0	0	0	0	1	0	1	0	0
100	30	15	14	1	0	14	6	5	5	29	1	0
Totals	47	24	20	3	1	23	12	7	5	42	4	1

comes established in the formation in which the well is located a rapid increase in its content is expected to occur. Fifty percent of the nitrate-nitrogen values are in excess of the amount normally assumed to indicate satisfactory sanitary quality. Five of the nitrate-nitrogen values were in excess of that recommended for preparation of infant formula.

Fifty-six percent of the wells between 65 and 75 feet from cesspools and 50 percent of those in the 100-foot range showed the presence of ABS. It is our belief that protective distances, unless extreme, are no assurance of the freedom of a well from ABS, and this is supported by the sampling data shown in the tables. It should be noted, however, that the greater concentration occurred at the shorter protective distance; thus, greater plot density results in increased pollution.

The depths to static water levels of the 47 wells were reviewed in relationship to the intensity and frequency of occurrence of ABS, nitrates, and free ammonia. The review indicated the frequency of occurrence of ABS is the same for depths ranging from 2 to 12 feet, from 14 to 23 feet, and from 30 to 35 feet. The concentrations of ABS and free ammonia were greatest in the 2- to 12-foot range and lowest in the 30- to 35-foot range. The greater concentrations of nitrates, however, were in the 30- to 35-foot range. These results are borne out by observations that in an area where the depth to the static water level is great complaints relative to syndets are infrequent. This is supported also by a study made by Mr. B.D. Andrez of C. W. Lauman & Co., Inc., on the appearance of ABS in the central portions of

Accumulated data indicate that any biological degradation in the subsurface discharge occurs principally in the unsaturated sand medium above the ground water table. Water from wells in areas where this sand layer is thin shows consistently greater amounts of the initial components of the nitrogen cycle, such as free ammonia and nitrites, than water from wells where there is a substantial layer of unsaturated sands above the ground water. It is also probable that a bacteriological survey would show a more frequent occurrence of coliform in areas with high water tables.

CORRECTIVE MEASURES

The need for public water supply facilities in the most intensely polluted areas has led to increased activities in the installation of public water supply facilities. Tens of thousands of homes in Suffolk County still use potentially hazardous individual well supplies; programs for extension of public water supply facilities are far behind the need.

Control of industrial wastes has been brought about by cooperation between the local building departments and the Suffolk County Health Department. New industries are denied building permits until plans for waste disposal have been approved.

The wastes from existing industrial plants have been detected through extensive Health Department surveys, and treatment facilities are under way for all known discharges. The 103 launderettes discharging wastes were ordered to provide treatment edly will be extended, since we are still in the process of determining an acceptable method for treatment of laundry wastes. Three types of packaged units have been specifically developed for treatment of launderette wastes, and one of each will be installed on a trial basis in the near future. The three basic systems thus far presented are a reactor-type unit, a flotation process, and a foaming process.

The reactor-type unit incorporates the use of activated carbon, alum, and a floc-aid. Waste is passed via a reactor-type device through a sludge blanket with a portion of the sludge continually removed to a dewatering tank containing leaf-type filters. The dewatered sludge has a solid content of approximately 10 to 15 percent. The accumulated sludge is reported to be less than 1 percent of the total waste volume. The system operates automatically and requires only a few minutes daily maintenance.

The flotation unit utilizes pH reduction, followed by flocculation in the presence of continually rising air bubbles. The pH reduction is obtained by use of sulphuric acid. Alum and a soap solution are used as coagulating agents. The alum, soap solution, and acid are injected by reagent feeders as the wastes enter the flotation unit. Aeration is accomplished by an aspirator on a high-speed centrifugal pump that circulates clarified effluent to the lower portion of the unit. Sludge is floated to the top of the unit and compacted as it rises through a conical upper section. The sludge overflowing the top of the tank is discharged downward into a sludge dewatering tank. The volume of sludge is less than 1 percent of the initial volume of the waste.

The foaming process is under development. The waste is foamed by aeration devices, and the foam overflows into a defoaming tank. The defoaming is to be accomplished by a low-speed paddle mechanism or by burning. The spent foam would contain the undesirable substances found in the initial waste. The spent foam or sludge is reported to have a volume of 10 percent of that of the waste. This presents a sludge removal problem for the operator, and efforts therefore, are being made to reduce this volume. The foaming system does not require the use of chemicals in the first portion of the operation. The Health Department will, however, require effluent polishing by activated carbon filtration to preclude discharge of taste producing substances.

All three systems substantially reduce the amount of ABS and BOD, by some 80 to 95 percent. The foaming system has an added advantage in that it also reduces the total dissolved solids by 30 to 50 percent. Costs of these three systems vary from $8,000 to $10,000 for a 20-unit launderette. Operating costs are said to vary from 1-1/2 to 3 cents per wash.

In addition to the measures already reported, a program has been started that should lead to a comprehensive sewerage plan for Suffolk County. Only through the medium of public sewers can ground water be effectively protected against contamination. Unfortunately, many years will pass before this plan is completed.

COMMENTS AND CONCLUSIONS

Ground water is extremely vulnerable to contamination by the introduction of industrial and domestic wastes into subsurface leaching systems. This is evidenced by the numerous incidents of contamination that are constantly being brought to light by complaints and spot check water quality surveys. The recuperative powers of the ground water are weak. A limited amount of biological degradation of organic wastes takes place in the unsaturated sands above the water table; however, available evidence indicates the level of biological activity in the saturated sands is low. None of the waters from contaminated strata in Suffolk County is known to have improved in quality following treatment or cessation of a contaminating waste discharge. Reuse of water is not a new problem to users of surface supplies, and methods of supply and treatment may be attuned to water reuse. In Suffolk County, treatment of individual well waters is nonexistent and of public waters negligible; thus, the hazards involved in the use of water of deteriorating or suspect quality is increasing. If it becomes our philosophy to continue to contaminate and then reuse our ground waters, our concepts of treatment and quality control must be completely revised.

The growth rates in the suburbs of Suffolk County have had a devastating effect on ground water quality. In the past when plot densities were lower, contamination was slight and area was available to relocate sources of supply where underground contaminants could be evaded. In the heavily populated areas of today, space to dodge our neighbors' underground sewage discharges is not available.

The nature of the waste introduced into our ground water changes as rapidly as new products are produced by our chemical industries. These wastes become firmly intrenched in our ground water long before we have an opportunity to evaluate their effect.

The Glacial stratum, the first recipient of our waste, is the only one thus far to exhibit the effects of contaminants. There appears to be a willingness to abandon this Glacial stratum to pollution under the unfounded opinion that the Magothy and Lloyd strata are safe from contamination and will provide sufficient water for future needs. Experiences thus far indicates that these deeper strata are unaffected; however, the volumes of waste are too enormous, the nature too complex, and our knowledge of the problem too meager to safely conclude that these strata will remain unaffected. In addition, unrestricted and continual pollution of the most readily available and most prolific source of water is scarcely consistent with good planning for disposition of vital natural resources.

RECOMMENDATIONS

1. Public water supplies must be extended to furnish water of known satisfactory quality to areas where water of unknown or hazardous quality from individual supply systems is being used.

2. Public sewage collection and disposal systems must be installed to end pollution of our ground water.

3. The treatment and disposal of all industrial wastes must be adquately controlled.

4. The quality of the ground water must be continually monitored through effective sample collection and laboratory tests.

5. Research programs on all phases of ground water pollution must be instituted and continued.

REFERENCES

1. New York State Water Pollution Control Board, Research Report No. 6. Andres, B. and Flynn, J.

2. Study on Ground Water Contamination - Town of Brookhaven. By Suffolk County Health Department - Villa, R. and Flynn, J.

3. Report on Status of Ground Water Quality and Related Factors in Suffolk County. Flynn, J. and Davids, H.

4. Study of Synthetic Detergents in Ground Water. Flynn, J., Andreoli, A., and Guerrera, A.

5. Survey of Industrial Wastes - Town of Babylon. By Suffolk County Health Department - Flynn, J. and Andreoli, A.

PROBLEMS ARISING FROM GROUND WATER CONTAMINATION BY SEWAGE LAGOONS AT TIETON, WASHINGTON

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This paper describes the unwitting contamination of several private water supplies near Tieton, Washington, a small farming community approximately 15 miles northwest of Yakima. The situation began with the conception, design, and construction of the town's sewage treatment facilities, and subsequently has lead to a court of law and an acrimonious debate between local citizens and the community. The dispute involves alleged contamination of nearby ground waters by Tieton as a result of its sewage disposal operation.

The writer first became acquainted with the problem after it had become a matter of litigation. Factual data and information are limited. The early history of the situation, particularly that relating to design considerations and engineering study of the area, is vague and uncertain. Even under the most favorable circumstances it is often difficult to define accurately the character and extent of ground water contamination. Consequently, much of the discussion that follows is based on interpretation of local conditions in light of well-established general principles.

Sewage Disposal Operation

Tieton disposes of its sewage by means of a nonoverflow lagoon located approximately 0.6 miles south of town. The lagoon was first placed in operation in April 1957. It was designed to dispose of the domestic, commercial, and industrial wastes of the community through the combined effects of evaporation and percolation. Prior to 1957 the community disposed of its wastes by means of septic tanks. Thus domestic wastes have been admitted to local ground waters over a diffuse area for several years, but at a location 3000 to 4000 feet northwest of the lagoon. The lagoon actually serves, in effect, to concentrate the community's wastes at a new location.

Although the lagoon was intended to function as a nonoverflow operation, the remaining design criteria employed are for the most part unknown. Neither the owner nor the engineer has described any material basis for design other than the assumption that the maximum percolation rate would be 0.25 inch per day (1). Similarly, it is not known what allowances, if any, were made for future service area expansion. Initially 124 households and 17 public, commercial, and industrial establishments were connected to the system. The present service area population is approximately 650. A typical rural community of this size might reasonably be expected to produce an average sewage flow of 50,000 to 60,000 gallons per day.

The lagoon as constructed consists of two cells having areas of 1.96 and 2.86 acres. One cell was intended to operate at depths ranging from 4 to 8 feet; the other was to operate at depths from 3 to 5 feet. Net evaporation in this area of Washington equals approximately 3.5 feet per year; this is equivalent to an annual average evaporation loss of about 3200 gallons per acre per day. Clearly, much of the original sewage volume, together with soluble and colloidal constituents, must exit by infiltration into the surrounding ground. The Tieton sewage disposal operation is in reality a spreading basin or seepage pit and not a lagoon or stabilization pond in the ordinarily accepted sense.

On May 20, 1958, the average daily sewage flow was reported to be 130,000 gallons of which 50,000 gallons was described as domestic sewage and the balance as infiltration and industrial was waters (1). With evaporative losses considered, an infiltration rate of about 0.9 inch per day over the entire 4.82 acres would be required to accommodate a flow of 130,000 gallons per day. The infiltration rate required to handle only the sewage flow component would be approximately 0.27 inch per day; this is very near the maximum infiltration rate of 0.25 inch per day reportedly employed as a basis for design. Evidently, sewage flows were in excess of those anticipated, and instead of the lagoon contents accumulating to the point of overflow, just the opposite occurred!

Initial infiltration rates as high as 18 inches per day were observed (1)! It was impossible to maintain water in either cell. Part of the difficulty was attributed to a leak in the lower dike. Even after the dike was repaired, however, it still was not possible to maintain water in both cells. Subsequently, sewage was admitted only to the cell into which the interceptor first empties. On May 20, 1958, more than 1 year after operation began, the infiltration rate was found to be approximately 3 inches per day (1). It was hoped that sewage solids would gradually seal the lagoon bottom, thereby decreasing the infiltration to a rate approaching the originally anticipated 0.25 inch per day. Apparently, the infiltration rate has decreased, for the water level after nearly 4 years of use has risen to approximately 3 feet.

Litigation

Two law suits were brought against Tieton for damages claimed as a result of invasion of ground water supplies by sewage in the vicinity of the Tieton lagoon. Both cases were tried before juries in the Superior Court of Yakima County. The first case, Pugsley vs. Tieton, came to trial in February 1959 and was concerned with pollution of a well approximately 250 feet south of and on property immediately adjacent to the Tieton lagoon. The second case, Cunningham et al. vs Tieton, was based on the joint claims of 6 additional owners of property located for the most part within 1500 feet of the lagoon; it was tried during October 1960.

In both cases the juries returned verdicts in favor of the plaintiff. For all except two of the parties in the Cunningham action, the jury found that the Tieton lagoon had adversely affected the ground water supplies of these people, at least to the extent that there was an element of doubt as to the potability of these waters. It was concluded that in their present condition and without some treatment these ground waters were no longer safe for human consumption.

The amount of damages awarded appeared to be based largely upon the influence ground water impairment had on the fair market value of the properties involved. In Pugsley vs Tieton, the plaintiff held that if the lagoon, by reason of odors or underground invasion of surrounding properties, deteriorated the value of adjacent properties there would be a taking or damaging within the meaning of the State of Washington Constitution (2). Both cases have been appealed and are pending before the Supreme Court of the State of Washington.

A second aspect of damage in the Pugsley case is that of a continuing nuisance, causing personal annoyance and inconvenience. In this regard, the plaintiff holds that a person can, as an item of damages wholly unconnected with the matter of depreciation in real estate value, recover for personal annoyance and inconvenience caused by the continuing nuisance resulting from the operation. The statute of limitations for nuisance is 2 years; hence, the plaintiff must initiate claims for damages every 2 years. Thus, it appears that Pugsley will continue to sue Tieton for nuisance damages at 2-year intervals or until the nuisance is abated or the operation ceases.

DISCUSSION

Biological Considerations

Failure on the part of sanitary engineers and public health officials to accept diluted treated sewage as a legitimate domestic water supply is merely a reflection of the doubts and uncertainties currently held regarding the potability of such waters. This position may seem a trifle naive in light of the situation now prevalent in many inland drainage basins where today's sewage literally serves as tomorrow's water supply downstream. It must be recognized, however, that where such conditions exist, these waters are subject to extensive treatment before consumption.

Perhaps the most serious and widely recognized hazard associated with domestic sewage is the possible presence of a number of pathogenic microorganisms. Recent evidence regarding the occurrence and persistence of viruses in domestic sewage adds still another element of doubt or reservation regarding the biological acceptability of treated and reclaimed sewages for human consumption (3).

Available evidence confirms what is intuitively obvious, namely that bacteria are quickly and effectively removed from sewage in passage through soil (4, 5). Unfortunately, a commonly held opinion that microorganisms rarely if ever penetrate more than 100 feet through continuous underground formations has assumed almost sacrosanct proportions. Obviously, the nature of the underground media through which ground water and sewage are free to move will determine the extent of bacterial penetrations. Circumstantial evidence was obtained by the Yakima County Health District (see Table 1) that indicates that E. coli traveled approximately 250 feet from the Tieton lagoon during the initial months of operation and entered a 160-foot-deep well.

Table 1. PRESUMPTIVE COLIFORM DATA - PUGSLEY WELL [a]

Date	Result	Date	Result
1/ 4/54	-	8/14/57	+
1/18/57	-	10/ 2/57	+
3/15/57	-	12/ 5/57	-
6/21/57 [b]	+	2/17/58	+
7/ 2/57	+	4/ 1/58	-
		5/21/58	-

[a] Results of bacterial examination conducted by the Yakima County Health District.

[b] Lagoon placed in operation in April 1957.

Topography, location, and subsequent detection of anionic surfactants further confirm the conclusion that seepage from the lagoon was entering the Pugsley well.

Enteric viruses by their very nature should be free to travel considerable distances underground. It appears that many species of virus can remain viable outside the human body for several days and in some cases for months (3). At the present time, there is absolutely no evidence that the coliform bacteriological test can be relied upon to describe the persistence of enteric viruses in ground water. It is simply unrealistic to employ the coliform test as the sole criterion for judging the biological quality of ground waters known to contain sewage. Other things being equal, travel time and dilution appear to be the principal factors affecting virus penetration; however, in the absence of specific information, it is not possible to interpret the quantitative significance of either of these factors. Obviously, the greater the travel time and the greater the dilution, the less the chance of virus contamination. Other factors, such as adsorption and deactivation by constituents within the aquifer, may serve to remove viruses from sewage-contaminated ground waters; unfortunately, data are not available at this time that permit evaluation of such phenomena.

Geological Characteristics

Tieton is located in a long narrow valley that terminates in a mountainous area some 25 miles northwest of Yakima. The valley is formed by a series of nearly parallel basalt anticlines. A series of permeable sands and gravels of fluviatile and glaciofluviatile origin overlie much of the basalt bedrock. The exact thickness of the permeable surface formations is unknown, but, judged from wells in the area and from the general geological characteristics of the region, it ranges from 20 to 200 feet throughout the valley.

The valley floor is broken occasionally by basalt outcroppings. Thin clay lenses have been found throughout the surface formation. Prior to construction, three 5-foot-deep test holes were dug at the lagoon site; the top 3 feet were described as sandy loam and the next 2 feet as sandy loam and gravel (1).

Ground Water Movement and Zone of Influence

In the vicinity of Tieton, the valley is drained by the North Fork of Cowiche Creek. The Cowiche Creek drains into the Naches River about 2 miles west of its confluence with the Yakima River. Ground water movement in the valley tends to be in the same general direction as surface drainage, more or less straight down the valley. The general direction of flow may be altered in some areas by waters entering from neighboring hillsides and by discontinuities such as basalt outcroppings, etc.

Two attempts were made to determine the rate and direction of ground water movement below the Tieton lagoon. During May 1958, state and local health officials, together with a commercial laboratory, investigated ground water movement by means of chloride (Cl$^-$) measurements (6). In January 1959, the writer analysed samples of well water collected throughout the area for anionic synthetic detergent content. Even though the data obtained during these field studies cannot be viewed as incontrovertible evidence of sewage contamination, they are nonetheless indicative of general ground water flow patterns in the vicinity of the Tieton lagoon. Results of the detergent survey are shown in Figure 1. Travel times calculated from the Cl$^-$ tracer study and the approximate zone of influence indicated by the detergent survey are shown in Figure 2.

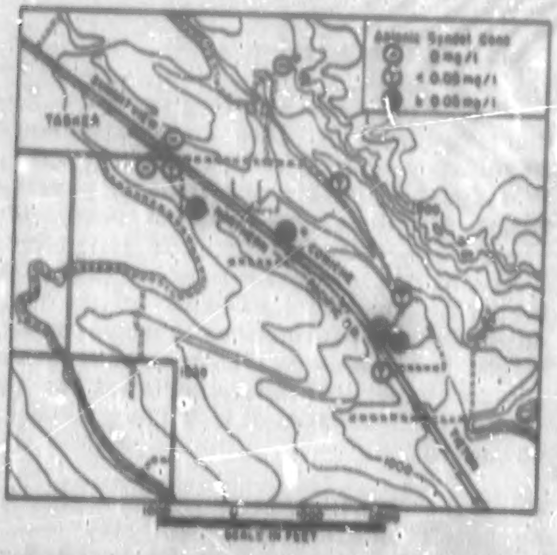

FIGURE 1. ANIONIC SYNTHETIC DETERGENTS IN DOWN-VALLEY WELL WATERS DEFINE GROUND WATER MOVEMENT AND PROBABLE EXTENT OF SEWAGE-INDUCED GROUND WATER MOUND

Sewage leaving the lagoon apparently tends to form a shallow elongated mound of water resting on top of the normal ground water table. Results of the Cl$^-$ tracer study indicate that velocities immediately below the lagoon are in excess of 300 feet per day! About 1000 feet farther down the valley the velocity decreases to approximately 200 feet per day.

Infiltration rates encountered during the first year's operation, 3 to 15 inches per day, indicate that the ground in this area is exceedingly porous. If preconstruction soil test data are typical for the general area, then it seems reasonable to expect relatively rapid ground water movement, near that indicated by the Cl$^-$ tracer study.

The zone of influence shown in Figure 2 is essentially a tentative evaluation of the

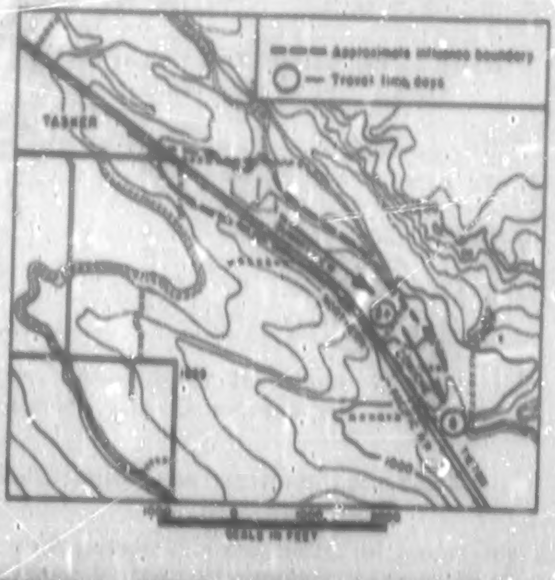

FIGURE 2. TIETON GROUND WATER ZONE OF INFLUENCE AND TRAVEL TIMES

extent and shape of the sewage mound in the vicinity of the lagoon. Some mixing and dilution of the sewage with ground water doubtlessly occurs down valley. Ultimately, a point will be reached where the residual effects or influence of the sewage are no longer significant. Just where the lower limits of ground water contamination lie in this case is unknown. Available information indicates that water originating in the Tieton sewage lagoon has reached rural ground water supplies as far as 1500 to 2000 feet down the valley in approximately 6 days.

In retrospect, it appears that little if any consideration was given to the influence of sewage infiltration on ground water quality. Indeed, it seems that even the infiltration characteristics of porous surface formations at the lagoon site were poorly understood. In principle, there is little difference between the conventional or more common practice of discharging wastes to surface waters and that of ground disposal. In either case, the waste disposal operation must be based on a thorough understanding of the self-purification characteristics of the receiving water mass and the effect of such action on subsequent water users.

REFERENCES

1. Answers to Interrogatories to the Defendant, No. 42005, Pugsley vs. Tieton, Superior Court of the State of Washington in and for Yakima County.
2. Private communication from Blaine Hopp Jr., Tenkoff, Hoist & Hopp, Attorneys at Law.
3. Clarke, N. A. and Chang, S. L., "Enteric Viruses in Sewage," Journal American Water Works Association, 51, 1299 (1959).
4. Butler, R. G., Orlob, G. T., and McGauhey, P. H., "Underground Movement of Bacterial and Chemical Pollutants," Journal American Water Works Association, 46, 97 (1954).
5. Krone, R. B., McGauhey, P. H., and Gotaas, H. B., "Direct Recharge of Ground Water with Sewage Effluents," Proceedings ASCE, Paper 1338, 83, August 1957.
6. Unpublished report G. H. Hanson, District Engineer Washington State Pollution Control Commission.

INFECTIOUS HEPATITIS OUTBREAK IN POSEN, MICHIGAN

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During the spring and early summer of 1959, an outbreak of infectious hepatitis occurred in the village of Posen, Michigan. Posen is a Polish Catholic community with an estimated population of 400. It is located in Presque Isle County in the northeast part of Michigan's lower peninsula.

The people in Posen as a whole form a very close community. An occasional trip to Rogers City or Alpena, the nearest communities of any size, is the extent of their normal travel. Community life centers around the church, the parochial and public schools, the Chamber of Commerce building, where wedding receptions, showers, and other social activities are held almost every weekend, and the local theater.

GEOLOGY AND HYDROLOGY

Geologically the area is very interesting. In the immediate area around Posen there is a thin veneer of glacial till, with a maximum thickness of 3 feet, overlying the bedrock. Outcroppings of rock are numerous throughout the area. The bedrock formations belong to the Traverse Group of the Devonian Age and consist mainly of limestones with some shale beds. These formations dip toward the center of the state at about 40 feet per mile.

No topographic maps of the Posen area are available, and without them, interpretation of the hydrology of the area is difficult. By use of the information available, however, the following general conclusions can be drawn regarding the hydrology.

A topographic high apparently extends through the Posen area in a northwest-southeast direction. This could be caused by some resistant limestone beds, within the Traverse Group, forming a low ridge paralleling the strike of the rock formations. The relief is not very great, but it is enough to be a controlling factor in the surface drainage. South of a northwest-southeast line through Posen, the streams drain southward, and north of this line they drain northward.

Water level measurements in wells indicate that Posen is situated on a ground water divide that trends in a northwest-southeast direction. This ground water divide conforms to the surface drainage pattern, and parallels the strike of the rock formations in the area. South of Posen, the ground water gradient is toward the southwest, and north of Posen, it is toward the north and northeast.

WATER SUPPLY

Posen has no public water supply and all the individual wells are drilled into the bedrock, where water is obtained from joints, fractures, and partings along the bedding planes of the limestone formations. The wells range in depth from 11 to 180 feet. The most usual depth ranges apparently are 30 to 40 feet, 50 to 70 feet, and 90 to 100 feet. Part of this wide range in the depth of wells is due to differences in elevation of the ground surface, and some of the deeper wells were probably attempts to obtain a "safe" water supply.

No relationship was apparent between the depth of wells and the quality of water. The observation, at one point in the investigations, was advanced that the majority of the contaminated wells were from 50 to 65 feet deep. When the data were compiled later, it was found that there was no correlation between depth of well and water safety.

Well Construction

A rather unique method of well construction is used in the area. All wells are 6 inches in diameter with casing that terminate at the ground surface. Most of the wells are cased to only a shallow depth, generally just through the glacial till and into the rock a short distance. The lengths of the casings range from 10 to 30 feet; and one well has no casing at all. Water was entering one well, for which the casing terminated at a shallow depth, from a shallow formation above the static water level and below the casing.

In many installations the casings were cut off at the ground sruface. Hand pumps were then installed on top of the casings, to be used during power outages. In practically all wells, however, no seal was installed between the hand pump drop pipe and the well casing, leaving the casing open for surface drainage. Where there was no hand pump, the well might be covered with some loose boards. Furthermore, no attempt was made to seal the bottom of the casing in the rock.

The power pumps were generally located in the basements of the homes with a suction line running out to the well casing. The portions of the construction features that were visible and conversations with the residents left little doubt that often the connection between the suction line and the well casing was not watertight. Accordingly, numerous opportunities for contamination resulted from the poor construction features - open top casings, unprotected suction lines, unsealed connections between suction lines and casings, and no seal between the bottom of the casings and the rock.

Location

As for location, most of the wells were too near septic tanks, tile fields, or seepage pits. This is particularly true when the thin veneer of soil on top of the limestone is considered. The excavation for the septic tank sometimes had been blasted out of the rock and the tile field laid in filled ground above the rock. Little doubt existed that septic tank effluent percolated vertically and then moved laterally for great distances, with little change in the characteristics of the effluent.

Water Quality

Laboratory tests of water samples from the wells substantiated the field observations. Thirty percent of the samples collected over the previous 3 or 4 years by the local health department had shown evidence of contamination. When the hepatitis cases began to appear, the well waters in the community were suspicioned as agents in the spread of the disease. During the investigation of the village wells a rather complete survey was made of all wells north of the corners. The survey was concentrated on the north side of the village, since practically no cases had appeared south of the main square of the village. As much information as possible was obtained about the construction of the wells and their location with respect to sources of contamination. Bacteriological analyses were made on all samples, and nitrates, nitrites, and detergents were checked on many. Within the village 47 percent of the samples showed the presence of coliform organisms. Forty-four percent of the wells were inadequately located with respect to sources of sewage pollution, and 70 percent had buried unprotected suction lines. Of the 10 wells checked for detergents, four were positive. One of these wells served the Chamber of Commerce building, which was frequently used for community affairs such as wedding receptions. A second well served the residence of the local durggist, and all the members of that family had suffered severe cases of hepatitis. The other two wells will be discussed in more detail later.

Weather Effects

The area had experienced subfreezing weather since Thanksgiving. For 3 consecutive days near the middle of March, however, temperatures rose to well above freezing and substantial melting of snow resulted. April 3 the village was blanketed by a 10-inch snowfall, followed by light rain. By April 15, all the snow was gone and run-off was complete. Wells in the village were producing a highly turbid water, which might be expected in view of the geology, the construction of the wells, and the heavy runoff. The local health department advised all residents to boil their water. Conditions were aggravated further during the first week in May by heavy rains; practically every basement in the community was flooded.

SPREAD OF THE DISEASE

Infectious hepatitis was reported first in the nearby community of Hillman in January 1959. The first cases appeared in Posen in the middle of April, apparently unrelated to those in Hillman. The "explosion" occurred in three families living in "Upper Posen," the north side of the community. About the middle of March one of the families was visited by a relative who, during his stay, became ill. The illness was diagnosed as infectious hepatitis. This visit coincided with the above-freezing temperatures that produced considerable run-off, later compounded by heavy snow and light rain.

The septic tank serving the home with the first hepatitis case was only 6 feet from the well. This well, like most of those in the community, had a 6-inch casing, driven to the shallow rock formation and cut off flush at the ground surface. A power pump was located in the basement and was connected to the well by a buried suction line. A hand pump was set over the casing, but was not sealed to provide a watertight joint. It was easy to understand how this well, so near the septic tank and so poorly constructed, had become contaminated.

The two houses immediately south of the one in which the first hepatitis case developed were served by one well, which was located only 10 feet from the septic tank on the first property. This well also was pumped through a suction line from the basement of the house. The top of the casing was "protected" by a couple of loose-fitting boards.

Within a 3-day period about 4 weeks after discovery of the first case of infectious hepatitis, 16 cases appeared in the three families. From this nucleus hepatitis spread rapidly through the community at epidemic proportions. Eighty-nine cases were reported; an epidemiological study showed later, however, that many cases were not reported. When one person in a household was diagnosed as having hepatitis, others in the household with similar symptoms were merely put to bed and no report made. Furthermore, it is very likely that many subclinical cases were not reported.

HYDROLOGY A FACTOR

Superimposed upon the ground water divide that runs through Posen is what appears to be a drawdown cone that reverses the natural flow of ground water. This results in ground water flowing into Posen from all directions, toward the low point of the cone of depression near the north central part of town. The existence of this drawdown cone is supported by the fact that numerous wells around the perimeter of the town yielded bacteriologically safe samples, whereas the wells within the village yielded a large percentage of unsafe samples.

As the ground water moves down the drawdown cone toward the center of the village, the fringe area wells intercept uncontaminated water. As the ground water continues down the cone, contamination from septic tanks, privies, sink drains, etc. is added. Since the ground water moves through fractures, partings along the bedding planes, and other openings in the limestone, little or no straining or filtration takes place and wells within the village intercept contaminated water.

The drawdown cone near the center of the village could be caused by either of two things. If the permeability of the aquifer in the Posen area is low, the combined pumpage from the concentration of domestic wells in the town may have deprived water levels locally and created the drawdown cone. The low permeability of the aquifer has since been verified by an automatic recording device that has been recording ground water elevations in a well near the center of town. The recorder showed daily fluctuations of 1 to 1.5 feet and seasonal changes from 6.5 to 10 feet. This is significant, since only low-capacity domestic pumps are used in this area.

The second possible explanation for the drawdown cone is that in the town there is a deep uncased well that penetrates a water-bearing formation in the limestone that has an artesian pressure surface lower than the water level in the upper formations. Ground water, under these conditions, would migrate from the upper water-bearing formations down the well bore into the lower water-bearing formation. This would create a drawdown cone in the upper formation from which the wells in the town extract their supply.

A well more than 300 feet deep is reported to exist in the village; however, this well was never located. A 300-foot well in Posen would probably penetrate the Rogers City limestone. The 80-foot thickness of Bell shale overlying the Rogers City limestone would constitute an effective aquiclude, and the artesian pressure surface in the Rogers City limestone could be lower than the water level in the Traverse formations. An uncased well that passes through the Traverse limestone and the Bell shale and penetrates the Rogers City limestone might account for the drawdown cone that apparently exists in the water table of the shallower Traverse limestones.

CORRECTIVE MEASURES

This discussion certainly has indicated that Posen has a water supply problem. Correction of the problem on an individual basis would be nearly impossible. The small size of the lots and the innumerable sources of contamination make adequate isolation of wells virtually impossible. Also, isolation is impractical because of the lack of natural purification of water in the area as it travels through the limestone.

The best solution to the water problem in Posen probably is the construction of a municipal water supply. Great care would be needed in the selection of the proper site for any municipal wells. First consideration probably would be given to the area on the south side of the village. Posen officials have had an engineering study made and a report prepared on the construction of a municipal water system; however, little further progress has been made, since any project would be costly because of the rock excavation necessary in the construction of a distribution system.

A bill introduced in the current session of the Michigan Legislature is designed to prevent situations like that in Posen. The bill provides for the licensing of well drillers by the State Health Commissioner and issuance of permits before wells are drilled.

SUMMARY

An outbreak of infectious hepatitis occurred in the northern part of Posen, Michigan, in 1959. Epidemiological studies indicated rather clearly that the first 16 cases were water-borne. The outbreak progressed rapidly south of the initial "explosion" and continued toward the center of the village where the progress of the disease was sharply curtailed.

The pattern of the disease conformed to a developed theory of the hydrology of the area. The virus apparently was introduced into the ground water through septic tank effluent on the north side of the community. According to the theory, melting snow and spring rains then flushed the virus through fractures in the limestone to the water table where it spread laterally. The virus moved southward down an inverted cone to the north central part of the town, infecting wells along the way. After reaching the low point in the drawdown cone, the virus could travel no further, probably accounting in part for the rather sudden decrease in the number of cases south of the center of the village.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Norman Papadorf, Sanitary Engineer, Michigan Department of Health, for his field study and to L. David Johnson, Hydrogeologist, Geological Survey Division, Michigan Department of Conservation, for his assistance in evaluating the hydrology of the area.

GROUND WATER CONTAMINATION IN THE GREENSBURG OIL FIELD, KENTUCKY

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The Greensburg oil field is unusual among the newly developed oil fields in the United States. Its discovery and early development had all the flavor and excitement of some of the early discoveries in Texas and Oklahoma. The epic at Greensburg has been interesting as a spectacle to watch and as scientific phenomena to observe.

The Greensburg oil field occupies parts of Green and Taylor Counties, Kentucky (see Figure 1). The area is in the upper Green River basin about 140 miles south-southwest of Cincinnati and about 70 miles south of Louisville. Before the discovery of oil, it was a typically rural area of central Kentucky: sleepy, slow-moving, and much concerned with the price of tobacco, corn, and hogs. After nearly 40 years of unsuccessful drilling, very few men believed that oil could be obtained from the limestones underlying the area. In 1956 methods of bringing in this oil were discovered and used with success. Many of the early wells were only about 450 feet deep. Because only a simple water well driller's rig was needed, a well

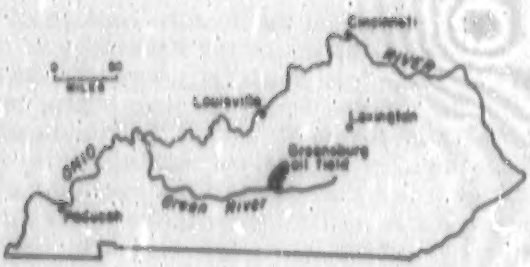

FIGURE 1. MAP OF KENTUCKY, SHOWING GREENSBURG OIL FIELD

could be put in for about $6000. The Greensburg oil field was, at the start, a poor man's oil field. By February 1960 over 2300 wells had been drilled. Some estimates place the number of wells at over 3000. The disposal of the brine pumped to the surface with the oil has been a difficult problem because of its volume and the methods of disposal.

Oil is obtained from the Laurel dolomite of Silurian age on the west flank of the Cincinnati arch. The oil pool that was outlined during the frantic drilling period during 1958 and 1959 covered an area about 25 miles long and 5 miles wide in Green and Taylor Counties. Since that time, the field has been slowly expanding, mostly in Taylor County.

A progress report on the effects of oil-field brines on surface and ground waters in the upper Green River basin was published by the Kentucky Geological Survey (Krieger and Hendrickson, 1960) in November 1960. This report also describes the geology of the upper Green River basin, the effects on the ground waters of Mammoth Cave, and the effects of various methods or procedures of brine disposal. The effect of the oil-field brines on the Green River was striking. The chemical character of the river water changed rapidly from a calcium magnesium bicarbonate water to a sodium chloride water. At Munfordville, about 50 miles downstream from Greensburg, chloride concentrations exceeded the 250-ppm limit of the U.S. Public Health Service drinking water standards 50 percent of the time. This affected the public water supplies of several towns and plans for an improved water supply at Mammoth Cave National Park. Drastic changes had to be made in water treatment methods at the gas-stripping plant of the Tennessee Gas Transmission Company at Gabe.

CAUSE OF THE POLLUTION PROBLEM

Kentucky is one of the oldest oil-producing states. Oil was discovered in Kentucky in 1819, but an organized search for it was delayed until about 1865. In 1959, Kentucky had its best year of oil production in the history of the Commonwealth. A total of 27,271,956 barrels of oil were produced. This was a 52 percent increase in production over 1958 and 7-1/2 percent of the total oil produced in Kentucky since 1918. The new Greensburg field produced 38-1/2 percent of all the oil produced in Kentucky in 1959. This surge in oil production, in combination with several other factors, produced the contamination problem.

First, the method of bringing in the oil was unusual. Drilling had produced a show of oil in the area for some time, but there was always the problem of disposal of the large quantities of brine brought in with the oil. It did not seem economically possible to develop such a field. In 1958 drillers learned that if a high capacity pump was installed and pumped hard, oil could eventually be brought into the well in profitable amounts. To achieve oil production by this method, brine had to be pumped from the well continuously at a high rate for several weeks or even several months before oil appeared. Even then the brine-to-oil ratio was unusually high. According to estimates, 3 to 20 barrels of brine are produced for each barrel of oil. The effect of this type of well development and oil production made it necessary to dispose of large quantities of brine.

Second, the well operators had the problem of disposing of large quantities of brine. At first, the easiest method of disposal was used. Brine was simply turned into the nearest ditch, creek, or drainage way. This polluted the creeks and the Green River. Many operators piped the brine into sink holes in the limestone. When forced to abandon these methods, so-called evaporation ponds were bulldozed out of the hillsides; however, most of the brine did not evaporate but ran freely out of the bottom of the ponds through fractures in the underlying limestone. Even disposal wells below the fresh water zone did not achieve their purpose because the brine could migrate upward into the zone of fresh water. The net result was a very rapid contamination of many water wells and springs with brine.

Third, the shallow depth of the oil-bearing strata made drilling relatively easy. Oil could be reached between about 400 and 700 feet. This meant that an oil well could be put in for only a few thousand dollars. All that was needed at many sites was the simple truck-mounted cable-tool rig of the water well driller. The Greensburg field became crowded with well drillers from Kentucky, Tennessee, and other states. Wildcatters were everywhere drilling in parking lots of drive-ins, front and back yards of homes, and in pastures and woods.

Fourth, Kentucky had never experienced an oil boom like this before and had no well spacing law, as it does now. Two or three wells on a half-acre became a common sight. Wells on adjacent leases were often so close together that, as someone said, "The drillers could shake hands." As a result, many more wells were put down than were needed to develop the field properly.

When the Governor called the Water Pollution Control Commission into the area, over 200 wells already had been drilled. Law enforcement became a real problem. Kentucky had an adequate, but relatively new, anti-pollution law in the statute books. Brine pollution, however, had not been tested or defined in the courts. Enforcement through trial and conviction in the local court was slow and difficult. The Kentucky Water Pollution Control Commission was literally swamped by the numbers of operators violating the pollution laws. Although the Commission established a field office at Greensburg and added men to the staff, full enforcement of the law was impossible because of the immense problem at hand. Time, appeals to higher courts, elimination of the small inexperienced operator, enactment of spacing laws by the 1960 Legislature, better means of disposal of brine all have contributed to a rapid decrease in the number of violations of pollution laws. The decline in oil production also helped reduce pollution; however, as a well declined in oil production, many operators pumped brine at higher rates in an effort to increase the flow of oil. Many of the early wildcatter wells are now out of production. In Taylor County, particularly, successful brine disposal through wells was hampered by leakage through old unplugged wells.

And fifth, since it was a poor man's oil field, mostly inexperienced or amateur

Table 1. OIL PRODUCTION - GREENSBURG OIL FIELD, KENTUCKY

Month	Barrels of oil, 1958 Green Co.	Barrels of oil, 1958 Taylor Co.	Barrels of oil, 1959 Green Co.	Barrels of oil, 1959 Taylor Co.	Barrels of oil, 1960 Green Co.	Barrels of oil, 1960 Taylor Co.
January	5,454		619,627	66	315,706	260,092
February	6,074		666,707	414	251,316	208,830
March	8,099		799,267	7,534	215,037	206,594
April	9,400		1,128,806	19,777	286,460	212,115
May	13,216		1,386,904	54,704	272,5[illegible]	209,969
June	31,064		1,148,464	91,480	222,41[illegible]	179,199
July	56,270		889,331	106,015	209,066	156,821
August	68,181		733,331	146,729	193,099	134,066
September	161,[illegible]		663,966	140,714	166,841	101,547
October	308,959		556,772	180,6[illegible]	148,909	92,036
November	468,558		465,111	190,9[illegible]	115,023	75,264
December	556,181		381,194	206,068	108,428	48,502
Total	1,646,040	a	9,417,460	1,093,966	2,577,663	1,790,484

a Negligible.

operators were working the field. The sudden development of the field surprised the larger and more established oil companies. Conservation by spacing and controlled pumping were not practiced. The inexperienced operators were more interested in immediate high production than in long-term yields. It was a matter, in many places, of pumping out your oil before your neighbor did. All-out pumping rapidly brought the field to peak production, as shown in Table 1.

This combination of circumstances is unlikely to occur again in Kentucky. The omission of any one or more of the factors would have greatly reduced the pollution problem.

WATER QUALITY BEFORE CONTAMINATION

Before development of the Greensburg oil field, fresh water was obtained from relatively shallow wells and springs. Wells were usually less than 100 feet deep, with bailers to supply water for domestic use in town, village, and on the farm. Many springs in the area had been dependable water supplies for home and farm for generations. The larger towns, Greensburg and Campbellsville, use surface waters as sources of public supply.

Shallow ground water in Green and Taylor Counties that has not been contaminated by brine is hard and low in Chloride. Analyses of a few wells and springs in Green and Taylor Counties are given in Table 2.

These analyses show a range in hardness from 185 to 485 ppm and in chloride from 1.2 to 36 ppm. Almost half the samples contained sulfate in amounts from 125 to 197 ppm. Except for hardness, the water has been suitable for most domestic and farm uses. Most water wells are equipped with bailers rather than pumps because of the cost of a pump, the low yield of the wells, and the widespread use of cisterns to supplement ground water supplies. If pumps had been used, it is probable that the chloride concentrations in some wells would have been higher.

WATER QUALITY AFTER CONTAMINATION

Chemical Character of the Brines

To determine the chemical character and strength of the contaminating material, chemical analyses were made of brines from a few oil wells. Analyses of six samples from wells in Green and Taylor Counties are given in Table 3. These samples average

Table 2. CHEMICAL CHARACTER OF UNCONTAMINATED GROUND WATER - GREEN AND TAYLOR COUNTIES, KENTUCKY

Well No.	County	Source	Depth, ft	Date sampled	Chemical analysis, ppm Bicarbonate (HCO_3)	 Sulfate (SO_4)	 Chloride (Cl)	 Hardness as $CaCO_3$ (Ca, Mg)	Specific conductance, µ mhos at 25°C
5586-9786-1	Green	Spring	--	11/17/55	222	9.9	1.2	206	381
5-2087.7-387.8	Green	Spring	--	11/18/55	204	6.9	1.5	185	345
5-2044.9-838.2	Green	Spring	--	10/28/55	248	12	10	229	463
5-2044.8-841.6	Green	Well	66.5	10/28/55	267	14	4.5	240	444
5-2068.1-839.8	Green	Well	92.3	11/18/55	344	156	5.0	450	791
5-2087.2-842.6	Green	Well	58	10/28/55	358	125	25	416	757
5-2075.7-876.1	Green	Well	40.4	5/18/60	286	9.0	7.0	262	484
5-2078.6-896.3	Green	Well	73	11/18/55	344	191	32	485	977
5-2080.9-860.3	Green	Well	40.9	11/18/55	396	217	36	461	1060
5-2084.9-808.7	Green	Well	33.6	11/17/55	430	58	8.0	425	742
5-2106.8-841.0	Taylor	Well	62.8	11/ 4/55	312	1468	23	1760	2550
5-2126.8-857.0	Taylor	Well	49.4	11/ 4/55	164	6.2	4.5	154	290
5-2123.2-896.6	Taylor	Well	30	11/ 4/55	236	79	6.9	221	556

Table 3. CHEMICAL ANALYSES OF OIL WELL BRINES - GREEN AND TAYLOR COUNTIES, KENTUCKY

Well No.	Depth, ft	Date Sampled	Chemical analysis, ppm				Dissolved solids [a]	Specific conductance, µ mhos at 25°C	Specific gravity
			Bicarbonate (HCO$_3$)	Sulfate (SO$_4$)	Chloride (Cl)	Hardness as CaCO$_3$ (Ca, Mg)			
12 K-49	--	10/18/57	48	211	68,300	19,200	105,000	119,000	1.074
11 I-46	551	5/ 7/58	--	--	80,300	--	134,000	152,000	1.101
7 I-48	--	10/18/57	81	1,210	75,900	34,700	126,000	132,000	1.090
S-2063.9-344.8	--	2/16/60	107	588	67,000	21,800	--	118,000	1.088
S-2077.4-347.0	327	10/25/58	63	--	35,000	25,800	--	120,000	--
S-2083.2-372.8	380	4/ 6/59	--	--	68,300	--	105,000	130,000	1.072

[a] Residue after evaporation at 180°C.

about 73,900 ppm in chloride concentration and 1.09 in specific gravity. Although no samples from Green or Taylor Counties were reported by McGrain and Thomas (1951) and McGrain (1953), the brine samples reported by them generally contained less chloride than those from the Greensburg field. In addition, most of the brines reported by McGrain were from deeper formations. Brine, in the range of 60,000 to 85,000 ppm chloride, is the contaminating material in the fresh waters of the Greensburg oil field.

Chemical Character of Springs and Wells

Very soon after intensive drilling started in Green County, water wells and springs became contaminated with brine. The salty taste of brine and the appearance and musty odor of oil were the first signs of contamination reported by local residents. The concentration of brine increased so rapidly in some wells and springs that some farmers had little chance to cope with the problem before their water supplies were made completely unpotable for man and livestock.

Table 4 contains the results of analyses of water from a few selected wells and springs made over a period of about 2 years. All of the wells were originally used to supply water for the home or for livestock. Some springs had been reliable sources of good water for several generations.

The rapidity and range of the change in chloride concentration stands out in comparing chloride concentrations for some springs or wells. When waste brines entered a well or spring, contamination often reached a peak concentration in a very short time. Natural flushing out or decontamination is noticeable, but it proceeds more slowly. For example, well S-2058.3-341.5 was a satisfactory source for domestic and farm use. By October 23, 1958, the chloride concentration had reached 41,000 ppm, but in a year had declined to 1,490 ppm. In 1960 the chloride concentration had increased again to 18,700 ppm, due, possibly, to contamination from new oil wells or changes in methods of brine disposal. The chloride concentration has since declined again to 705 ppm.

Well S-2077.8-379.5 was potable domestic water well equipped with a bailer. Water from the well reached at least 49,400 ppm chloride. Such a chloride value represents a dilution of about one-half to less than one-third. Spring No. S-2080.8-380.9 not only showed brine contamination but also showed evidence of oil pollution.

Contamination of ground water supplies extended to Brownsville, about 100 miles downstream from Greensburg. In October 1959, the city well at Brownsville yielded a sample containing 405 ppm chloride, compared with 2.5 ppm in September 1957. In June 1960, the chloride concentration of the water was diluted to 130 ppm by the increased flow of the river.

Table 4. CHEMICAL ANALYSES OF CONTAMINATED WELLS AND SPRINGS - GREENSBURG OIL FIELD, KENTUCKY

Well data	Date sampled	Water level, ft below LSD	Chloride, ppm	Remarks
82057.2-342.6; WBF; Miss. ls.; Drilled well; 58 feet deep, 6 inches in diameter.	10/23/58	49.27	25	Original use; domestic Abandoned because of high chloride content.
	3/30/59	--	7,960	
	6/25/59	51.66	1,180	
	10/ 7/59	50.69	675	
	6/16/60	51.16	448	
	2/ 9/61	45.99	70	
82059.3-341.5; WBF; Meramec ls.; Spring.	10/23/58	--	41,000	Original use; domestic stock. Not used. Chickens appeared to be drinking this water on 2/9/61.
	6/25/59	--	4,890	
	10/ 7/59	--	1,490	
	4/24/60	--	7,840	
	6/16/60	--	18,700	
	2/ 9/61	--	706	
82064.7-339.4; WBF; Meramec (?); Drilled well; 25 feet deep, 6 inches in diameter.	10/23/58	18.09	1,090	Original use; domestic.
	6/26/59	18.00	8,250	
	10/ 7/59	18.25	9,580	
	6/16/60	18.40	5,400	
82064.3-340.4; WBF; Meramec (?); Drilled well; 58 feet deep, 6 inches in diameter.	10/23/58	58.0	14	Original use; domestic. Not used, polluted.
	4/28/59	--	10,500	
	6/27/59	51.0	7,990	
	10/ 7/59	51.13	6,770	
82076.7-347.8; WBF; - ; Drilled well; 347 feet deep, 6-1/4 inches in diameter.	10/24/58	Flowing	1,800	Original use; stock.
	10/ 8/60	Flowing	181	
	4/24/60	Flowing	120	
82077.8-379.5; WBF; Miss. ls.; Drilled well; 40 feet deep.	10/ 9/59	Flowing	10,900	Original use; domestic.
	12/21/59	Flowing	49,400	
	7/21/60	8.56	980	
	9/ 8/60	--	1,960	
82079.6-392.1; WBF; Miss. ls.; Spring	6/ 8/60	--	21,100	Original use; stock.
	8/ 5/60	--	13,600	
	9/ 8/60	--	28,400	
82080.8-380.9; WBF; Miss. ls.; Spring	3/ 9/60	--	9,370	Original use; domestic stock. Slight oil slick on surface. Abandoned.
	4/19/60	--	6,120	
	7/21/60	--	10,900	
	9/15/60	--	6,770	

The contamination problem wrought various degrees of hardship on the local residents. Many farmers had to develop another water supply, where possible, or haul water for domestic or stock use. More dependence was put on cisterns for domestic water supplies. In any case, fresh potable water became scarce. In an area more suitable for dairy and beef cattle than cultivation of field crops, the short supply of water often meant getting rid of the livestock.

Total Amount of Brine Contamination

It is difficult to make a reliable estimate of the amount of brine pumped in the Greensburg oil field since oil production started in early 1958. Very few records were kept by the wildcatters, and brine disposal was too often a dark-of-the-moon operation. Fortunately, it was fairly easy to measure the quantity of salt draining from the Greensburg oil field.

The Greensburg oil field is entirely within the upper Green River drainage basin. Water discharge from this area is measured by a recording gage at Munfordville, about 20 miles downstream from Greensburg. The U. S. Geological Survey and the Kentucky Geological Survey, fortunately had maintained a daily sampling station at Munfordville since October 1949. Reliable measurements could be made of the load of brine being discharged out of the oil field. In the 1959 water year, 296,000 tons of chloride were discharged from the Greensburg field. This is equivalent to about 23,300,000 barrels of brine, compared to 10,600,000 barrels of oil produced in 1959. Brine production in the field is undoubtedly greater because drainage values do not allow for evaporation, detention in the rocks, and the lag between pumpage and drainage. In 1960, brine, as measured by drainage at Munfordville, was about the same as in 1959, but oil production had declined to 4,470,000 barrels.

WATER QUALITY NOW AND IN THE FUTURE

Enforcement of the pollution control law, enactment of a well spacing law, and decline of production has produced some improvement in quality of the shallow ground waters in the Greensburg oil field. At least some springs and wells are below their peak chloride concentrations. A few wells and springs are being used again, but some of this may be partly a matter of adaptation to a new set of conditions.

What of the future - say 5, 10, or 20 years from now? One thing seems certain - chloride concentrations in some wells and springs will be above the normal maximum of 30 to 35 ppm for some time to come. Personally, I feel a bit optimistic about the future quality of the ground water. The sink holes, solution channels, and fractures in the rock, which made pollution of wells and springs so easy, should also help in flushing out the bulk of the contaminating brines. As production declines to a level that will be more nearly the long-term average for the field, the source of contamination will be largely removed. Optimism, however, should be tempered by realization that corroding well casings will allow brine to seep into fresh water aquifers. The history of other oil fields indicates that complete recovery is many, many years away. Yet, I believe that in a few years water quality in some areas will reach a level acceptable for livestock and possibly for domestic use.

REFERENCES

1. Krieger, R. A. and Hendrickson, G. E. Effects of Greensburg oil field brines on the streams, wells and springs of the upper Green River basin, Kentucky. Ky. Geol. Survey, Report of Investigations No. 2, series X, 1960, Lexington.

2. McGrain, Preston. Miscellaneous analyses of Kentucky brines. Ky. Geol. Survey, Report of Investigations, No. 7, series IX, 1953, Lexington.

3. McGrain, Preston and Thomas, G. R. Preliminary report on the natural brines of eastern Kentucky. Ky. Geol. Survey, Report of Investigations, No. 3, series IX, 1951, Lexington.

INCIDENTS OF CHROMIUM CONTAMINATION OF GROUND WATER IN MICHIGAN*

M. Deutsch, U.S. Geological Survey

Our ground water resources in some areas have been contaminated in many different ways and by many different contaminants. A review of numerous incidents of ground water contamination in Michigan by the author (1) revealed how easily aquifers can become contaminated, how widespread and costly such contamination already is, and how difficult it is to remove contamination once introduced. The review also outlined principles controlling the entry and movement of wastes in aquifers. Among the most serious (and interesting) cases reviewed were those involving entry of chromium compounds, especially hexavalent chromium, into aquifers used as sources of public supply.

The chromium-contamination incidents demonstrate a few of the ways wastes may enter an aquifer. These incidents serve as examples of the seriousness of ground water contamination. They provide us with an opportunity to examine the hydrogeologic controls that govern the underground movement of the contaminants and also give us some insight concerning the extent and duration of the effects of contamination of our ground water resources.

Electroplating, especially chrome plating, is a relatively small but important industry in Michigan. The industry has the problem of disposing of plating wastes, which are variable in character and usually include hexavalent chromium, cyanide, and caustic soda in the rinse waters. Of particular concern with respect to plating wastes is the fact that minute concentrations of hexavalent chromium and cyanide render water unfit for human consumption. According to the U. S. Public Health Service (2), "hexavalent chromium in excess of 0.05 ppm (1 part to 20 million) shall constitute grounds for rejection of the (public-water) supply." The toxicology laboratory of the Michigan Department of Health reported that chromium in the amount of 1 ppm may have a detrimental effect on the human nervous system and kidney tissues and that chronic illnesses may result. The chromate imparts a yellow tinge to the water in which it is dissolved. Cyanide in any amount whatsoever is intolerable in water used for public supply.

In the past, disposal of electroplating wastes to streams has created serious hazards to the public health. As an alternative to surface disposal of electroplating wastes, some concerns have attempted to dispose of the wastes in infiltration pits. This practice has some merit in that the hazard from cyanide reportedly is largely eliminated. The Michigan Water Resources Commission observed that although they "have encountered a number of ground-water-pollution problems involving electroplating wastes, no instance has occurred . . . where cyanide could be traced in wells any distance from the point of disposal. This is accounted for by the various reactions to which cyanide is subjected by subsurface formations."

PERCOLATION FROM PONDS

Disposal of the waste to the ground has not solved the chromium-contamination problem, however, since chromium is not completely removed from the water by the rock materials through which it percolates. Almost all the suspended solid material is filtered out by the first few inches of soil, but the water containing dissolved chromium moves through the permeable materials and reaches the aquifers. In general, the movement is downward, although some water is dispersed laterally by capillarity or deflected by lenses or zones of low permeability. Eventually, the contaminated water enters the upper part of the underlying aquifer (Figure 1). (All the figures included in this paper are schematic and are not based on field data.) The liquid waste tends to form a mound on the water surface and moves radially from the mound. The direction and

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* Approved for publication by the Director, U.S. Geological Survey.

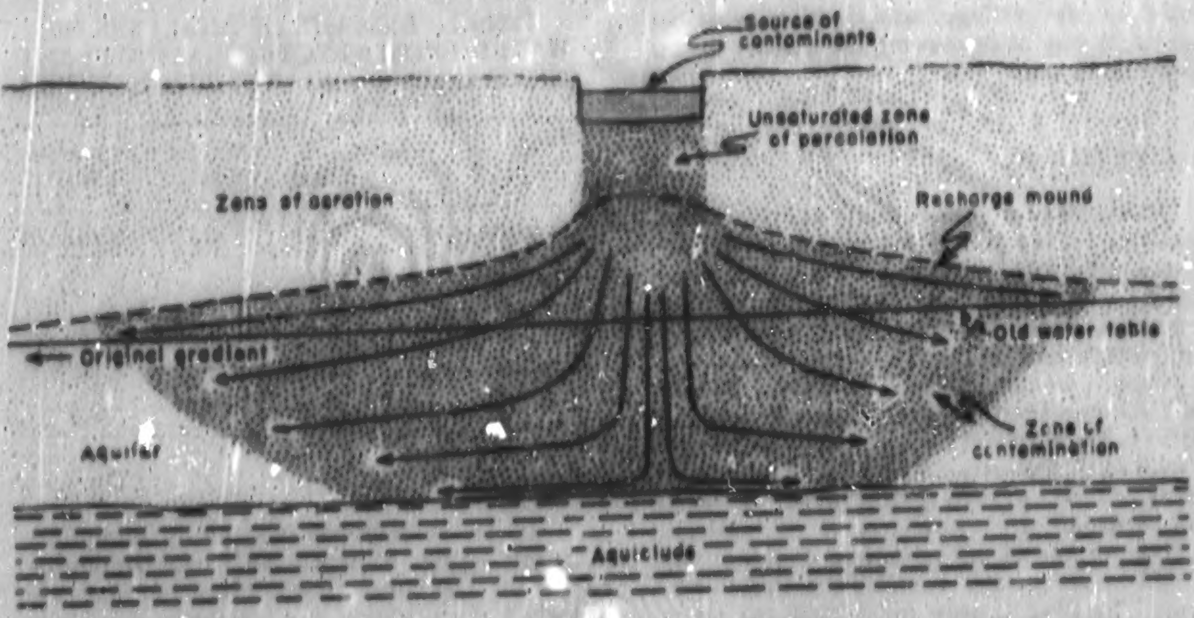

FIGURE 1. SCHEMATIC DIAGRAM SHOWING PERCOLATION OF CONTAMINANTS THROUGH ZONE OF AERATION AND INTO ISOTROPIC AQUIFERS

velocity of underflow of the waste is controlled principally by the gradient and the permeability of the aquifer materials. Once the chromium is introduced, the aquifer is unfit as a source of potable water for a prolonged period of time because of the generally slow movement of ground water. It is not known whether natural flushing action or dewatering by pumping will in time remove the chromium from the aquifer.

Douglas Incident

Several instances of chromium contamination have occurred in the State. In 1947 the Michigan Department of Health (3) was notified that water from wells tapping the glacial drift in the western part of the village of Douglas in Allegan County had turned yellow. The wells were removed from service, pending analysis of a water sample. The analysis revealed a chromate content of 10.8 ppm or more than 200 times the concentration of hexavalent chromium recommended by the Public Health Service as the maximum safe limit in public supply systems.

The source of contamination was quickly located. About 3 years before the contamination appeared, a metal-plating concern began discharging chrome-plating wastes into an infiltration pit and the surrounding overflow area about 1000 feet south of the western wells and 2500 feet southwest of the eastern well at Douglas. Discharge of the plating wastes had resulted in contamination of the glacial-drift aquifer for at least 1000 feet in one direction from the pit and to a depth of at least 37 feet. It had taken about 3 years for the waste to migrate 1000 feet at a rate of about 1 foot per day along the gradient created by pumping of the western wells. Health Department personnel estimated at the time that if disposal to the pit were stopped immediately it would be at least 6 years before the aquifer in the vicinity of the west wells would be free of chromate. Although the 1947 analyses of water from the eastern well showed no chromate content, water from the well was analyzed periodically as a safeguard. However, the wells of a local dairy were found to be contaminated. The Health Department requested that the Village Council condemn all private wells in the village, since there was no practical way of observing the quality of the water from each well.

Bronson Incident

Since 1939 electroplating industries at Bronson, in southern Michigan, have experienced difficulty in disposing of electroplating wastes (4). Originally, the wastes were discharged into the city's sewer system, which emptied into a county drain and a creek. Contamination of these watercourses resulted in the death of fish and cattle below Bronson as a result of ingestion of cyanide. The city subsequently issued an ordinance to prohibit discharge of toxic wastes to the city's sewer systems. All the plating wastes of the principal company involved subsequently were discharged to two ponds. In 1942 it was found that the dikes around the ponds were unsafe, and inspection of the flow from the sewer system revealed a faint yellow color, characteristic of chromium-waste contamination. The chromium probably resulted from leakage of water from the ponds, both above and below ground, or use of the sewer system for waste disposal. Subsequent cases of surface water contamination were reported.

In 1949 ground water contamination at Bronson was revealed when the owner of a domestic well observed a "greenish tinge" in his well water. The well was 75 feet from the sewer that carried plating wastes to the disposal ponds. In December of 1949 the Water Resources Commission collected samples of water from one of the ponds from the domestic well, and from a well at the County Highway Garage between the pond and the domestic well. The domestic well was 14 feet deep, and the water level was 8 feet 6 inches below the land surface. The well at the garage was 33 feet deep, and the water level was 8 feet 2 inches below the land surface. Both wells tapped the same shallow glacial-drift aquifer. Results of the analyses made by the Michigan Department of Health are given in Table 1.

Table 1. RESULTS OF ANALYSES OF WATER FROM ELECTROPLATING PLANT DISPOSAL POND AND TWO NEARBY WELLS

	Pond	Garage Well	Domestic Well
Cyanide, ppm	15.6	0	Trace
Chromium, ppm	6.0	0	2.0
Nickel, ppm	49.0	0	Trace
Copper, ppm	12.0	0	0
pH	6.65	7.5	7.5

It was evident that the part of the aquifer tapped by the domestic well was contaminated at the time of sampling but that the deeper part, which was tapped by the Highway Garage well, was not. A check of the sewer lines revealed that they were in good condition and were not contributing contamination to the aquifer. Evidently, the plating wastes were moving directly from the disposal ponds. By December 29, 1949, the chromium content of the domestic well had risen to 3.5 ppm.

Several interesting hydrologic observations can be made, based on the instance of chromium contamination at Bronson. The chemical analyses revealed that the 33-foot well at the County Garage was not contaminated at the time the sample was collected, although the well is between the contaminated shallow domestic well and the disposal pond. This shows that the chromium contamination was not uniformly distributed throughout the aquifer. The contaminant may have been confined to the upper part of the ground water body and only slightly dispersed in traveling through the aquifer. Movement to the deeper well could have been impeded in part by lenses of low permeability within the aquifer.

The natural gradient of the water table in the shallow-drift aquifer was reported to be northwestward, but the contaminated well was southwest of the disposal pond. This indicates that a ground water mound was built up that moved the wastes in a direction opposite to the natural gradient. Underground movement of contaminated water would tend to be radial from beneath the pond (Figure 2).

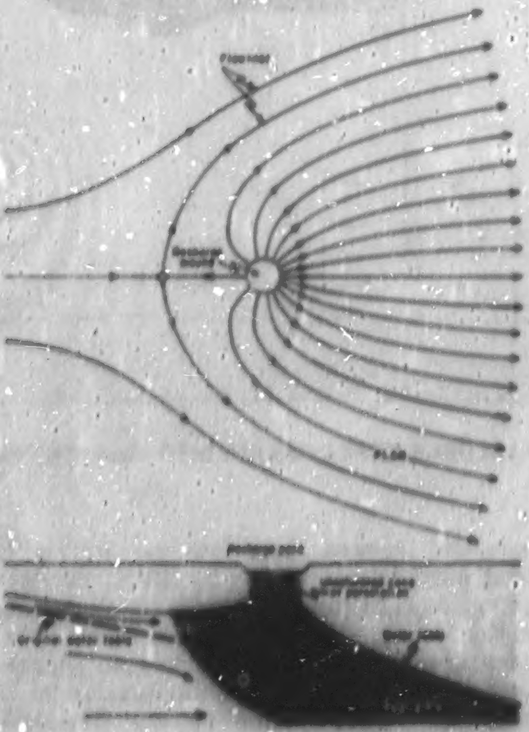

FIGURE 2. DIAGRAMS SHOWING LINES OF FLOW FROM MOUND ON SLOPING WATER TABLE

The degree of buildup of the mound and hence the distance the water moves opposite to the natural gradient is controlled by the slope of the natural gradient, the physical character of the aquifer, and the quantity of contaminated water introduced. (Pumping of wells also would result in local gradients opposite to the natural gradient. Thus areas upgradient from sources of contamination are not necessarily protected from pollution.)

After more than a decade, there is concern that new wells proposed to be drilled to a deeper aquifer by the city also might be subject to chromium contamination. The lower aquifer is reported to be separated from the contaminated upper aquifer by a "thick impervious clay stratum." The concern that deeper wells may be contaminated may be warranted, however. Aquifer tests made in numerous areas of the State by the Federal and State Geological Surveys seldom reveal artesian conditions perfect enough to completely shut off all interaquifer movement of water. Study of the well logs or even visual inspection of a clay layer is inadequate to determine the impermeability of clayey materials. Laboratory analysis of permeability or extensive aquifer testing would be necessary to determine the hydraulic characteristics of the "impervious clay stratum." Further, it would have to be determined whether the confining layer is penetrated by wells with rusted or broken casings that would permit leakage of contaminants to the lower aquifer (Figure 3).

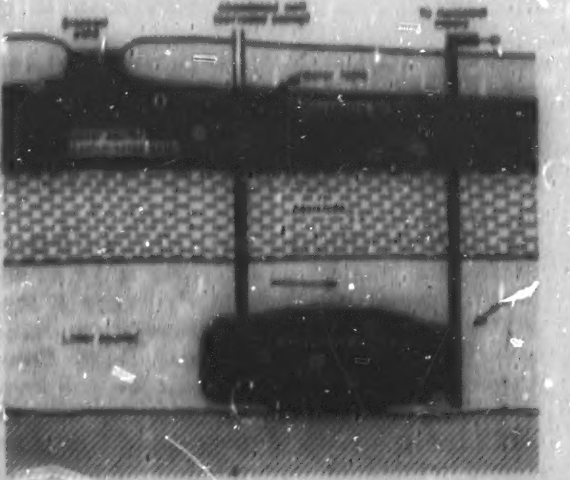

FIGURE 3. GENERALIZED DIAGRAM SHOWING INTERFORMATIONAL LEAKAGE BY VERTICAL MOVEMENT OF WATER THROUGH WELLS

LEACHING FROM THE LAND SURFACE

Kent County Incident

Several incidents of ground water contamination have resulted from uncontrolled spilling or spreading of chromium-bearing substances on the land surface. Disposal of chrome-bearing liquids or soluble solids that can percolate to an underlying aquifer are a

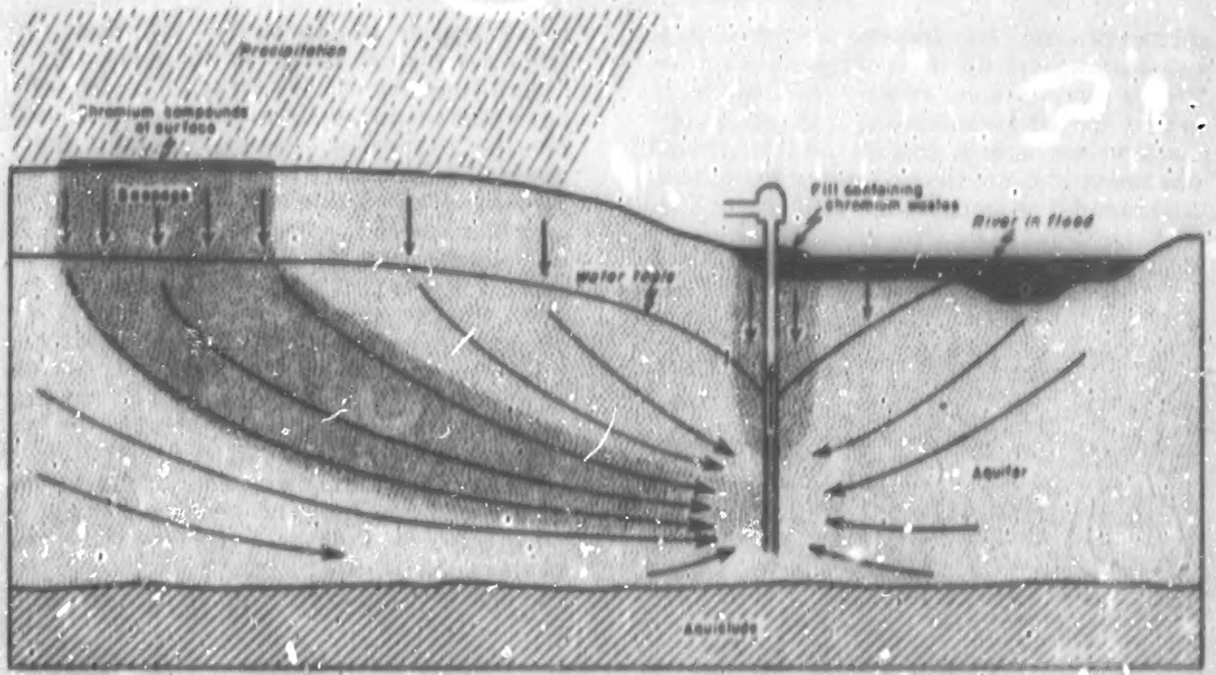

FIGURE 4. SCHEMATIC DIAGRAM SHOWING LEACHING OF SOLUBLE CONTAMINANTS INTO AQUIFER FROM PRECIPITATION AND FLOOD WATERS

potential hazard, as illustrated by Figure 4. An incident in Kent County (5) indicates how chromium contaminants can be spread on the surface through "normal" activities. During the winter of 1955-56, some of the snow along a roadside in the area turned yellow. Investigation by a township engineer revealed that the Kent County Road Commission was using salt to melt ice and snow on the county roads. The salt was treated with a chromium-base rust inhibitor to allay county residents' complaints concerning rapid corrosion of automobile bodies. Samples of snow had a chromium content of 10 ppm. Fortunately, the township engineer recognized the potential hazard to the water supplies of the area and notified the County Road Commission; the use of chromium-treated salt was promptly discontinued.

A unique case of ground water contamination by chromium occurred in the city of Grandville west of Grand Rapids (6). In this incident the city drilled a public supply well in the glacial-drift deposits along the Grand River. To protect the well from flooding during periods of high water, the casing was extended several feet into the air and the land surface was raised by filling with sand and gravel. In time, chromium was detected in the water. This resulted in considerable consternation, since there was no apparent source of chromium contamination in the vicinity. Investigation by the Grandville Superintendent of Water revealed that the sand and gravel fill used to raise the land surface at the well was taken from a former dumping grounds for electroplating wastes. The river was in flood stage shortly before the contamination appeared. Water from the river obviously had leached the chromium from the fill and carried it into the aquifer.

DISCHARGE OF CHROME-LADEN DUST

Wyoming Township Incident

For several years Wyoming Township in Kent County had difficulty obtaining from one of its well fields water that was free from chromium. An electroplating firm on adjacent property was the apparent source of the chromium contamination. Accordingly, the

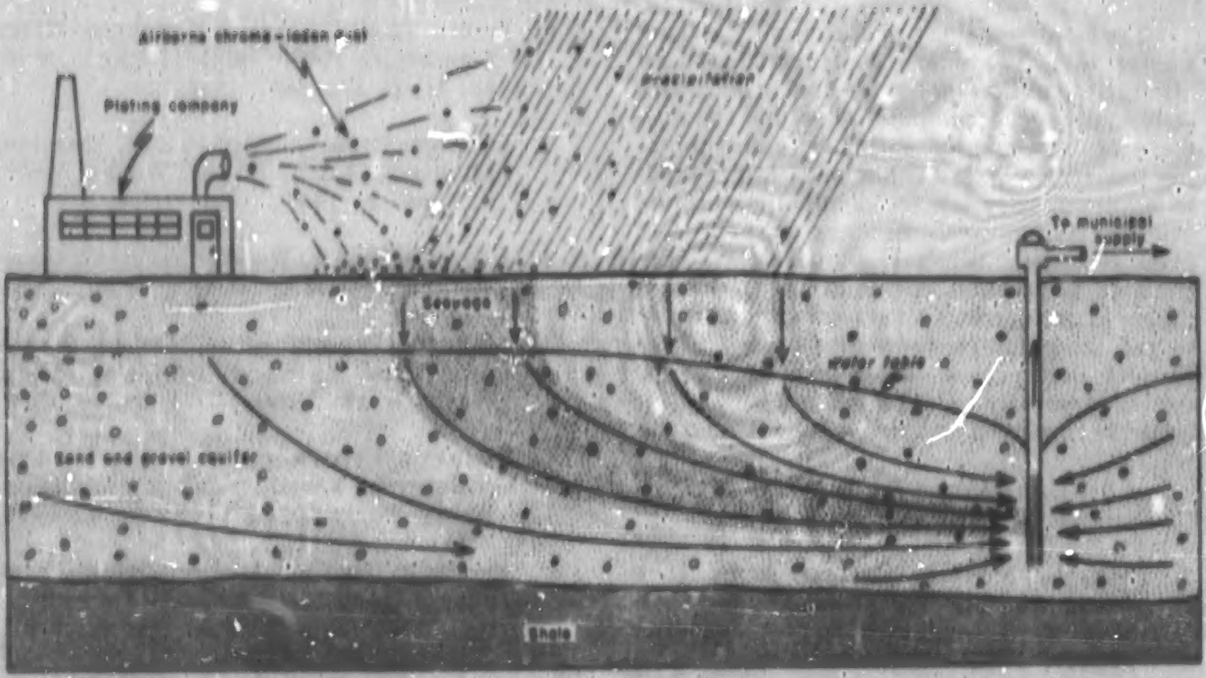

FIGURE 3. DIAGRAM SHOWING POSSIBLE MODE OF ENTRY OF AIRBORNE WASTES TO AQUIFER

firm retained a consulting engineer to study the problem and report on the possibility of further contamination and of means of abatement (7).

The engineer concluded in his study that airborne chromium could have been introduced to the aquifer in several ways. Chrome-laden dust was discharged through ventilators on the roof. Some of the dust settled to the ground, where it accumulated until rainfall washed it down to the water table, as depicted in Figure 3. A general relationship was shown between precipitation and chromium contamination in the township wells.

A dry well at the site, into which water from the roof on the plant drained, was another likely source of intermittent contamination. Some of the dust probably was washed out of the air and onto the roof by precipitation. The dust may have flowed down a rainspout into the dry well and then infiltrated to the aquifer, through which it subsequently migrated to the well field in response to pumping.

In addition, the Michigan Geological Survey reported that chrome-powder residue was present in or on containers left in the yard. Some of this hazardous powder may have been spilled on the ground from where it readily could have been leached and carried into the underlying aquifer by subsequent rainfall.

SUMMARY

Several incidents of chromium contamination of ground water have occurred in Michigan. The most serious of these resulted from disposal of electroplating wastes to ponds or settling basins. Other incidents of ground water contamination were caused by spreading of chromium-treated salt to melt snow, by use of chromium-contaminated land fill, and possibly even by settling of chromium-laden dust from the air. Fortunately, chromium contamination of ground water has been of small areal extent, and no human fatalities or serious illnesses are known to have occurred.

The modes of entry of chromium-bearing wastes to aquifers are well recognized by Michigan public agencies concerned with water resources and public health. Through their efforts, contamination by electroplating industries virtually has been eliminated. In addition, very few incidents of contamination by chromium from other sources have been reported. Because minute concentrations of hexavalent chromium in water are highly toxic, aquifers must be constantly protected from future contamination. To help protect our ground water resources, the public generally must be made aware of the hazards involved in the disposal of toxic wastes.

REFERENCES

1. Deutsch, Morris, Ground-water contamination and legal controls in Michigan. U. S. Geological Survey open-file report. 1960.
2. Public Health Service Drinking Water Standards. Public Health Reports, v. 6, no. 11, p. 371-384. 1946.
3. Michigan Department of Health. Douglas, Michigan. Mich. Water Works News, v. 7, no. 3. 1947.
4. L. A. Darling v. Water Resources Commission (341 Mich. 654).
5. Michigan Department of Health. Inhibitors used in snow removal. Mich. Water Works News, v. 23, no. 2. 1958.
6. Michigan Department of Health. Unique pollution of a well by chromium. Mich. Water Works News, v. 21, no. 3. 1956.
7. Report to the Grand Rapids Brass Company on industrial wastes and water supply. Williams and Works mimeo. rept., Grand Rapids, 1956.

REFUSE DISPOSAL, ITS SIGNIFICANCE

L. Weaver, Sanitary Engineering Center

Approximately 4 pounds of refuse per capita per day are produced in the United States. The term refuse, as used here, refers to the useless, unused, unwanted, or discarded solid waste materials resulting from normal community activities; refuse includes such materials as garbage, rubbish, ashes, street refuse, dead animals, and solid industrial wastes (1). Thus, every day our urban population produces over 400,000,000 pounds of refuse that must be disposed of by dumping on land, grinding and disposal with sewage, incineration or that must be made reusable by one or more reclamation processes. Over 1400 communities dispose of their refuse by sanitary landfill techniques, i.e., compaction and covering with compacted

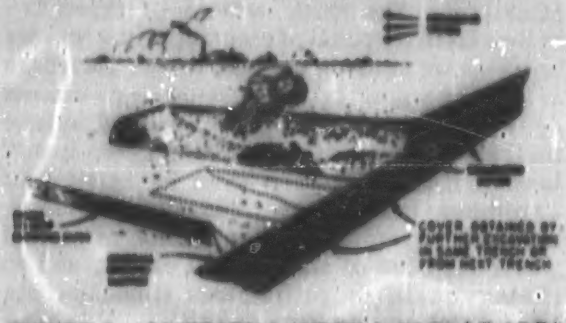

FIGURE 1. SANITARY LANDFILL IN FLAT AREA

FIGURE 2. BURNING OPEN DUMP

earth on suitable land by use of mechanical equipment such as crawler type tractors (Figure 1). Many thousands more dispose of this material in open dumps on land without the degree of sanitary control recommended by health agencies (Figure 2).

Wherever refuse is deposited on land, the potential impact on surface waters or subterranean aquifers may be significant. This can be better appreciated when one considers, for example, that ordinary community refuse may have a 5-day BOD of 14,000 to 180,000 ppm and an alkalinity (to MO as $CaCO_3$) of 2600 to more than 23,000 ppm, as shown in Table 1(2). In one study bacteriological examination of landfill material showed an average of 740,000 coliforms per gram of refuse. The leachate from a landfill has been found to have a 5-day BOD from 6 to more than 7000 ppm(3, 4).

The question is, of course, what does this mean translated into terms of potential ground water pollution? And further, when this potential is known, what then are the practicalities involved in present disposal practices and their implications with respect to the development of existing and future ground water pollution problems?

THE POTENTIAL PROBLEM

For pollution of ground water by refuse leaching, three basic conditions must exist: (1) the refuse fill must be located over, adjacent to, or in an aquifer; (2) a state of supersaturation must occur within the fill - this may occur because of the movement of ground water into the fill from percolation of precipitation and surface water runoff, from water of decomposition, or from an artificial source; (3) leached fluids must be produced and this leachate must be capable of entering an aquifer (10).

Table 1. CHEMICAL ANALYSIS RESULTS [a]

Analysis	Refuse ready for burial											Sample buried	
Date sample collected	3/8/50	3/6/50	4/12/50	5/10/50	6/6/50	7/18/50	8/21/50	9/19/50	11/17/50	12/18/50	Average	1 year 7/18/50	2 years 7/14/51
Total solids, %	53.33	51.41	44.06	51.44	60.35	49.35	46.36	31.58	37.81	29.36	44.60	37.07	66.1
Volatile solids, %	31.69	20.18	17.23	15.28	36.53	16.88	27.46	13.71	20.07	23.12	22.52	11.96	21.5
Fixed solids, %	21.65	31.23	26.83	36.16	20.82	26.37	18.82	17.82	17.74	6.24	22.26	25.43	44.6
pH	5.9	7.77	9.2	6.4	5.0	6.2	6.8	7.4	4.9	5.5	6.5	6.0	6.6
Acidity to PP as $CaCO_3$, ppm	756	188	128	840	3,540	923	3,000	2,064	3,378	6,910	2,299	1,262	145
Alkalinity to MO as $CaCO_3$, ppm	14,350	8,282	19,780	7,740	10,825	2,867	21,000	13,000	28,100	17,180	16,133	737	2,800
Ammonia as N, N, ppm	252	144	66	120	840	263	408	500	73	164	280	390	163
Total nitrogen as N, ppm	6,045	3,140	2,846	1,380	10,115	5,460	6,128	8,070	5,623	6,960	6,557	3,116	2,090
Oxygen consumed, ppm	294,020	200,000	170,080	168,800	301,500	256,000	294,000	167,000	227,000	268,480	270,975	208,000	230,000
5-day BOD, ppm	96,900	65,000	39,000	14,000	178,800	41,000	105,000	39,000	70,000	130,000	77,050	35,000	32,600

[a] Public Health Service and North Dakota State Department of Health Study, "Sanitary Landfill Study at Mandan, N. D."; analyses made at Robt. A. Taft Sanitary Engineering Center.

Sound engineering practice in site selection can prevent the coexistence of conditions (1) and (2). Condition (3) could be brought about by a combination of water externally applied for compaction of refuse, water of decomposition, rainfall, and surface runoff. It is highly improbable that any of these except the water used for compaction would provide sufficient water to produce a state of supersaturation in a sanitary landfill. An open dump, however, is another matter. After the capacity of a fill site is exhausted and the area is reclaimed, surface sources of water for potential leaching are rainfall, runoff, and irrigation and subsurface sources are high ground water levels due to artificial or natural recharge of aquifers and possible breaks in water mains or sewers that might have been laid in the refuse fill. If leaching of a landfill does occur, it has been shown that ground water in the immediate vicinity can become grossly polluted and unfit for human or animal consumption or for industrial and irrigational use. Where essentially anaerobic conditions exist in a landfill, the decomposition of organic matter results in the formation of gases, principally methane, carbon dioxide, ammonia, and hydrogen sulfide. Methane, due to its slight solubility and low density (specific gravity 0.55; air = 1.0), diffuses vertically. Hydrogen sulfide, although present in relatively small amount, gives the leach-polluted waters an offensive taste and odor; however, subsequent dilution by oxygen-containing ground water and atmospheric oxygen diffusing into the landfill oxidize the sulfides to tasteless and odorless sulfur and sulfates. Carbon dioxide, due to its high solubility, combines with water to form carbonic acid and will dissolve iron from tin cans and lime from calcareous materials and deposits. Chemically, the effects of carbon dioxide and ammonia are the most significant products of decomposition of organic matter in a landfill operation. Carbon dioxide increases the hardness of the water, and ammonia, on oxidation, increases its nitrate content.

A discussion of the implications of refuse and ground water pollution in the United States would be grossly incomplete if attention was not given to the classic investigations that have been accomplished during the past decade and are continuing under the direction of Professor Robert C. Merz of the University of Southern California. Professor Merz's work was carried out under contract with the California State Water Pollution Control Board and included investigations of leaching from ash dumps as well as from a sanitary landfill. The investigation of ash dumps established that percolation of natural precipitation, or the movement of ground water through an incinerator ash dump, will leach soluble salts and alkalies from the dump (5). This study also showed that over a 5-year period the maximum amount of any cation that may be reasonably expected to be leached from an incinerator ash dump will be 2.9 pounds per cubic yard (sodium) and the maximum amount of any anion 5.3 pounds per cubic yard (chloride). In addition, much interesting information has been collected in an investigation of leaching from a sanitary landfill in Riverside, California (6). It was found, for example, that a sanitary landfill in intermittent or continuous contact with ground water will cause the ground water in the immediate vicinity to become grossly polluted and unfit for domestic or irrigation use:

> "Concentration of mineral elements varying from 20 times those commonly found in unpolluted ground water - up to 10,000 times in the case of ammonia nitrogen - are possible. Further it may be expected that continuous leaching of an acre-foot of a sanitary landfill will result in a minimum extraction of approximately 1.5 tons of sodium plus potassium, 1.0 tons of calcium plus magnesium, 0.91 tons of chloride, 0.23 tons of sulfate and 3.9 tons of bicarbonate. Leaching of these quantities take place in less than one year. Removals would continue with subsequent years, but at a very slow rate."

Table 2 lists the results of certain analyses of the aquifer located immediately below the Riverside Sanitary Landfill. Well No. 1 was the control well located "upstream" from the fill. Well No. 2 was one of a number dug within the fill area, and Well No. 3 was located some 900 feet below the 1952-53 fill area. The immediate and substantial effect on the aquifer below the fill itself is quite evident, e.g., the fourfold increase in

Table 2. ANALYSES OF SHALLOW GROUND WATER AQUIFER AFFECTED BY A SANITARY LANDFILL[a]
(All results except pH in ppm)

	Well No. 1	(control)	Well No. 2		Well No. 3	
	52-53	59-60	52-53	59-60	52-53	59-60
pH	7.10	7.20	6.86	6.90	7.23	7.28
Carbon dioxide	16		210		33	
Total hardness as $CaCO_3$	326	385	1070	815	610	330
Alkalinity as $CaCO_3$	285	335	1126	600	390	305
Calcium	99	128	260	155	180	97
Magnesium	18	22	100	81	36	17
Sodium	76	45	505	[illegible]	165	87
Potassium	5.2	5.0	26	13	6.8	13
Total iron	0.03	0.04	6.2	4.0	0.20	0.86
Ferrous iron	0.02		1.2		0.02	
Chloride	76	98	875	146	255	120
Sulfate	78	110	195	19	160	64
Phosphate, inorganic	0.06	0.04	0.11	1.9	0.29	1.6
Organic nitrogen	0.84	0.17	2.5	0.88	0.88	0.67
Ammonia nitrogen	0.18	00	0.88	1.9	0.51	1.4
BOD	2.3		36		0.97	

[a] Univ. of Southern California studies at Riverside, California. Average analyses of ground water samples from wells for period shown. Aquifer tested was located just below bottom of refuse fill. Well No. 1 (USC #9) was located about 1000 feet upstream from the fill area, Well No. 2 (USC #4) in the fill itself, and Well No. 3 (USC #13) about 900 feet below the 1952-53 fill area.

hardness in Well No. 2 and the almost two-fold increase at Well No. 3 - all at the end of one year. That the quality of the aquifer is affected even after 7 years is also evident (6, 7).

Experience in other countries substantiates these results. At Krefeld, Germany, for example, wet-tipping begun in 1913 was studied for its effect on ground water (8). Deterioration of the aquifer quality was observed at 5/8 mile in 1923 and at 4-3/4 miles 4 years later. Total hardness varied from 600 to 900 ppm $CaCO_3$ in the polluted wells, compared with 225 ppm in the original water. Sulfate (SO_4) and chloride (Cl) reached 395 and 263 ppm, respectively, but iron manganese and ammonia were found only in traces. Coliform bacteria were not found in any of the wells.

On consideration of this potential pollution, it must be reemphasized that so far we have discussed the impact of leachings from refuse to a shallow aquifer that intermittently comes in contact with the refuse itself. What of deeper aquifers? The answer to this is not necessarily clear cut. Certainly an adequate impervious layer can prevent pollutants from a contaminated area above from reaching the deep aquifer. Results of studies at Riverside, California, demonstrate the importance of geological formations. A test well downstream from the fill area revealed water of roughly comparable deteriorated quality at the 12- and 30-foot depths, but of better quality at the 62-foot depth than that from the control well upstream from the fill. The explanation for the deteriorated quality of the aquifer at the 30-foot level was that the impervious layer immediately below the shallow aquifer in the fill area is "probably a non-continuous one" (6).

Two aspects of pollution travel are pertinent here: the downward movement of bacteria and chemicals with percolating water and the lateral movement of such pollutants once they have entered the ground water. Butler, Orlob, and McGauhey concluded the following from their studies conducted at the University of California Sanitary Engineering Research Project at Berkeley(9):

> "Observers are generally in agreement that pollution is not appreciably extended laterally by percolating waters moving downward through soil above the ground water. The extent of vertical travel, therefore, becomes the more important factor in determining the public health danger involved in applying wastes of any given intensity of pollution to the soil and in defining the minimum safe distance between the ground surface and the water table."

Available information indicates that coliform organisms are effectively removed from percolating waste water. The movement of dissolved chemicals with percolating water is a different matter. It has been shown that chemical contaminants can travel many times farther in water than bacterial organisms. There are, of course, many aspects involved, including velocity of water movement and type of soil.

For purposes of this discussion, the data cited have necessarily been brief. Much additional interesting and pertinent information has been obtained from these and other studies. It cannot be denied, however, that the potential of refuse as a ground water pollutant is real. What then is the significance of this potential?

The Existing Problem

Recently the Solid Wastes Engineering Section of the American Society of Civil Engineers Committee on Sanitary Engineering Research undertook an extensive survey of sanitary landfill practices in the United States (11). Some 700 cities that have Class "A" Sanitary Landfill Operations* were queried, and more than 200 replied. Of the latter, 6% reported "water pollution" problems (Figure 3). Follow up contact with those who reported problems resulted in 5 replies. One described a temporary surface water pollution problem, since remedied, and two respondents denied any knowledge of ever having reported a problem. Two reports of shallow well pollution were verified; one of these reported that it was never really established that the landfill operation rather than a neighboring fruit-processing plant actually was the source of the contamination.

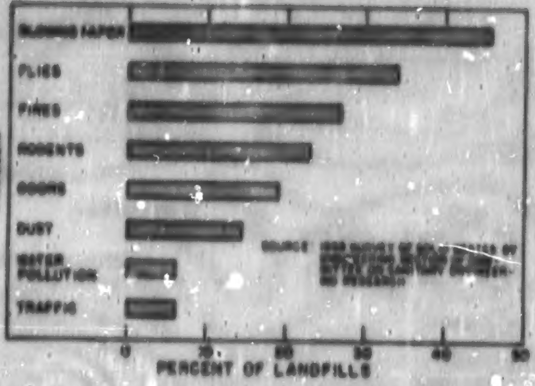

FIGURE 3. PROBLEMS WITH SANITARY LANDFILLS

Of the five replies to follow-up contacts, the one of real interest concerned a large city in the Southwest. The Public Health Engineer involved reported:

> "We have had two cases of ground water pollution caused by sanitary landfills in the city. Each of these cases occurred at the same time and happened in the spring of 1957.
>
> "The one case involved two private shallow wells and was caused by the ground water level rising up into the garbage in an abandoned gravel pit which was being used for a sanitary landfill. This pit was about twenty-feet deep and excavation was being made to ground water level to obtain cover dirt. These two forty-foot shallow wells were being used for domestic supply and became unusable when excessive rain caused the water table to rise into the sanitary fill. The city paid for the cost of extending the city water main to serve these houses and the wells were abandoned.

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*A Class "A" Sanitary Landfill is one operated without public nuisance or public health hazard; it is covered daily and adequately, and no deliberate burning practiced (12).

"The other case involved only one thirty-foot city owned well which served a picnic area. This well had to be abandoned for the same reasons as the two in the previously cited area.

"There were no other wells reported as being unusable in the vicinity of either of these two sanitary landfills except those previously mentioned.

"It should be noted that we do not approve of any well being used for domestic water supply which is less than one hundred feet in depth. Our experience has shown all the shallow wells which have been tested in the past have shown to be contaminated either intermittently or continually.

"The city obtains all of its water from deep artesian wells from the Edwards Limestone Formation which meets all U. S. Public Health Service Drinking Water Standards. The water from this formation has always been free of contamination from properly constructed wells."

It is of interest to note that this same survey included data showing that, of the cities that replied, 27 percent operated fills wherein the depth to ground water was from 0 to 5 feet (Figure 4).

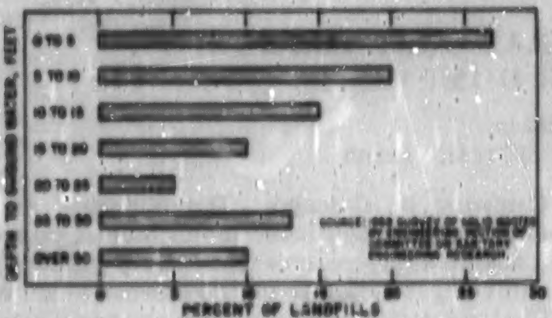

FIGURE 4. DEPTHS TO GROUND WATER FROM BOTTOMS OF SANITARY LANDFILLS

Conclusions

It is evident that refuse may be a source of organic, mineral, and bacteriological pollution. It has been demonstrated that, if a sanitary landfill or dump is so located that it will be in intermittent or continuous contact with ground water, it will cause that water in the immediate vicinity of the landfill to become grossly polluted and unfit for domestic or irrigation use. Bacterial and organic contamination may be very limited in range, but chemical pollution, i.e., mineral salts (chloride and hardness), may travel some distance before the effects of dilution are evident. Passage of landfill leachate through sand or gravel may be expected to improve conditions so far as bacterial and organic pollution is concerned, but chemical pollution can be expected to reach the ground water along with percolating water. Proper location and operating practices to prevent supersaturation of a fill are essential.

Data now available indicate that the pollution of ground water from a refuse source has been essentially limited to shallow aquifers but that deeper aquifers can be affected.

It is indeed encouraging to note that there are apparently hundreds of well-planned and properly operated sanitary fills where community refuse is being disposed of without public health hazard or nuisance. One cannot help wondering, however, about those that are not Class "A" operations and also about the unfortunately large number of communities that still resort to uncontrolled dumping. The impact of these practices on ground water and the other public health implications involved are cause for concern. We need to know much more about both geological and climatic characteristics that, along with operational techniques, are so important to short- and long-term effects of degradation and possible leaching of refuse disposed of on land. We also need to have a much clearer picture of conditions as they now exist in areas where refuse presently is being disposed of by landfilling.

Acknowledgments

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Williams, Head and member, respectively, of the Solid Wastes Engineering Section of the Sanitary Engineering Research Committee of the American Society of Civil Engineers.

REFERENCES

1. Refuse Collection Practice, 1958. American Public Works Assoc, 561 pp Public Administration Service, Chicago, Ill.

2. The sanitary landfill in northern States. Public Health Service Publication No. 226, Government Printing Office, Washington, D.C. 1952. 31 pp.

3. Carpenter, Lewis V. and Setter, Lloyd R. Some notes on sanitary landfills. American Journal of Public Health 30, 1940. 385 pp.

4. McDermott, G.N. Pollutional characteristics of landfill drainage. Report No. 3, January - March, 1950. Robert A. Taft Sanitary Engineering Center, Public Health Service.

5. Report on the investigation of leaching of ash dumps. State of California Water Pollution Control Board Publication No. 2, 1952.

6. Report on the investigation of leaching of a sanitary landfill. State of California Water Pollution Control Board Publication No. 10. 1954.

7. Report on continuation of an investigation of leaching from dumps. University of Southern California Engineering Center Report 72-3. June 1960.

8. Roessler, B. Translated by Zehnpfennig, R. Influence of garbage and rubbish dumps on ground water. Vom Wasser 18:43. 1950.

9. Butler, R. G., Orlob, G. T., and McGauhey, P.H. Underground movement of bacterial and chemical pollutants. American Water Works Association Journal. 46. 1954. p. 97.

10. Municipal Refuse Disposal. American Public Works Association, Public Administration Service, Chicago, Ill. In press.

11. Survey of Sanitary Landfill Practices in the United States. Solid Wastes Section, Committee on Sanitary Engineering Research, American Society of Civil Engineers. In press.

12. Weaver, Leo. Progress in refuse disposal. Public Works Engineers Newsletter 22:9, March 1957. p. 1.

UNDERGROUND NATURAL GAS STORAGE (HERSCHER DOME)

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The Herscher underground natural gas storage field is located about 1 mile south of the Village of Herscher in Kankakee County, Illinois, approximately 45 miles southwest of Chicago. This facility is of great importance to the integrated natural gas system that supplies the great Chicago region. The development work for the storage project was performed by the Natural Gas Storage Company of Illinois, which owns and operates the field and its facilities. The storage company is owned by Natural Gas Pipeline Company of America, which is a subsidiary of the Peoples Gas Light and Coke Company of Chicago. The company also owns and operates three major long-distance transmission pipelines that deliver gas from natural gas fields in the Southwest to serve Chicago and other places in a six-state area of the Middle West. The large-scale terminal storage of gas is needed to meet the peak demands imposed during the winter heating season and to use more efficiently the capacities of the transmission system. The structure has a potential storage capacity of 90 billion cubic feet of gas, and at present there are approximately 50 billion cubic feet in storage.

In post World War II years, consumer demands for space heating increased tremendously. Customers waiting for permits for gas numbered in the hundreds of thousands, and the Gas Transmission and Distributing Companies began investigations of means for storing the large quantities of gas that were available during the off-peak seasons. Preferably, storage should be in the immediate vicinity of Chicago, which was the area of greatest demand. Three possible choices of storage were studied: above-ground storage, below-ground storage in dense limestones mined to form cavernous rooms into which gas could be injected and withdrawn, and below-ground storage in a porous, permeable strata, permitting the injection and withdrawal of gas and overlain by a dense, impermeable dome-shaped rock formation. From a cost standpoint the last choice appeared preferable, and the Herscher field was explored by the Natural Gas Storage Company, which had been formed by the transmission pipeline companies and customer gas companies.

Since the Gas Storage Company formed did not qualify as a utility under the Public Utilities Act and could not exercise power of eminent domain, a new Act, entitled "Transportation, Distribution or Storage of Gas," was presented to and passed by the State Legislature. This Act provided for exercising the power of eminent domain under certain conditions and upon approval of the project by the Illinois Commerce Commission. For the Herscher project, approval of the State Sanitary Water Board was also required since that agency has jurisdiction over pollution of underground waters.

A petition was presented by the Natural Gas Storage Company to the Illinois Commerce Commission, requesting an order approving the Herscher proposal. The Commerce Commission called a public hearing, as required by law. The State Sanitary Water Board, State Water Survey Division, and State Geological Survey Division were all represented, as were property owners and others interested in the project. Since this was the first project of its type in Illinois, it stimulated considerable interest and resulted in much discussion on the technical aspects of the project, such as well construction, water movement in the aquifer, and geology of the reservoir and caprock. After a number of hearings and presentation of all arguments, the Commerce Commission rendered a decision favorable to the storage project. The Sanitary Water Board also gave its approval.

DESCRIPTION OF FIELD

The Herscher storage field is an aquifer that underlies some 15,000 acres of rural land. Geologically, the structure of the Herscher Dome (Figure 1) is a closed anticline, or dome, shaped like an inverted saucer that provides a geologic trap necessary for large scale storage of natural gas. The anticline is about 8-1/4 miles long and 4 miles wide at its broadest point. Deep within the geologic trap, 1750 feet below the ground surface, is the apex of a very porous and permeable bed of sandstone, known as the Galesville sand, which is the reservoir for the storage field. The Galesville stratum is approximately 100 feet thick and has the characteristics of a natural oil and gas field. The stratum is void of petroleum deposits however and contains only nonpotable water with approximately the following chemical constituents; chlorides, 500 ppm; hardness, 600 ppm; sulfates, 800 ppm; and residue, 1900 ppm.

Overlying the Galesville sand is the Ironton stratum of dense and impermeable dolomitic sandstone, which forms the caprock approximately 125 feet thick. This dome-shaped caprock covers some 8000 acres and has a vertical height of 200 feet beneath its apex. Above the dome are alternate formations of clastic rock units; shales, sandstones, limestones, and dolomites. Figure 1 illustrates the formations and the storage reservoir.

The existence of the structure has been known for many years. Following the turn of the century, some 18 shallow oil wells had been drilled to an average depth of 200 feet where oil and a small amount of gas were encountered. The yields were not of commercial importance, and after a short period of pumping, the wells were abandoned. No attempt was made to plug these wells, and farming was continued after the casings had

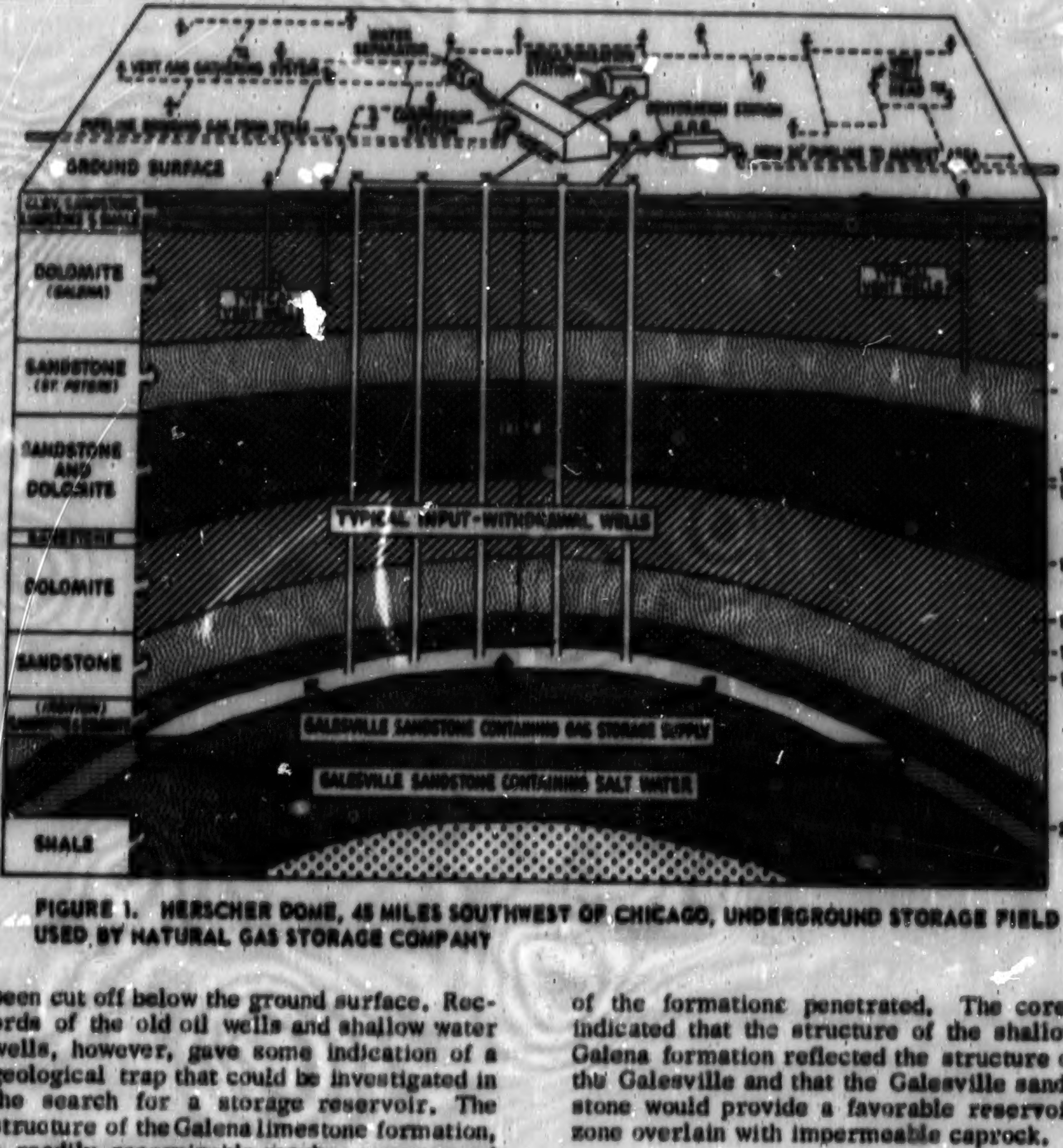
WATER SEPARATOR
GROUND SURFACE
DOLOMITE (GALENA)
SANDSTONE (ST. PETER)
SANDSTONE AND DOLOMITE
DOLOMITE
SANDSTONE
SHALE
TYPICAL INPUT-WITHDRAWAL WELLS
GALESVILLE SANDSTONE CONTAINING GAS STORAGE SUPPLY
GALESVILLE SANDSTONE CONTAINING SALT WATER
140'
1100'

FIGURE 1. HERSCHER DOME, 45 MILES SOUTHWEST OF CHICAGO, UNDERGROUND STORAGE FIELD USED BY NATURAL GAS STORAGE COMPANY

been cut off below the ground surface. Records of the old oil wells and shallow water wells, however, gave some indication of a geological trap that could be investigated in the search for a storage reservoir. The structure of the Galena limestone formation, a readily recognizable marker encountered from 150 to 350 feet below the surface, was further established by 104 shallow test holes. The subsurface positions of the Galena were contoured by use of data from the 104 holes, and a structural map of the top of the Galena was obtained. Four deep test holes were drilled and cored through the Galesville sandstone, and the cores tested to provide information on the porosity and permeability of the formations penetrated. The cores indicated that the structure of the shallow Galena formation reflected the structure of the Galesville and that the Galesville sandstone would provide a favorable reservoir zone overlain with impermeable caprock.

Twenty-one injection-withdrawal wells, spaced 660 feet apart, were completed in the Galesville sandstone on the crest of the structure. Thirteen observation wells were drilled into the structure to the top of the reservoir at down-dip positions on the flanks so that water levels could be observed and the movement and effect of the gas bubble that was to be created could be followed. These wells were all cased and cement-grouted from bottom to ground level.

Gas injection was started April 1, 1953. Two 150-hp compressors, with a total capacity of 15 million cubic feet per day, were used to overcome friction and the hydrostatic pressure in the formation.

On July 1, 1953, the main plant, with a 10,000-hp compressor station and a dehydration plant of 300 million cubic feet per day capacity, was put in service. Injection rates were stepped up to 200 million cubic feet per day.

MIGRATION OF GAS

During the last week of July 1953, after gas had been injected for 4 months and the gas bubble in storage was under all injection-withdrawal wells at a thickness relative to their positions on the structure, one of the shallow water wells in the town of Herscher began to bubble gas. Since this area some 30 years or more before had contained a small shallow accumulation of gas in the Divine limestone of the Maquoketa formation and the Galena dolomite formation and since various water wells in these formations had at frequent intervals through the years given up gas, it was not immediately a certainty that the gas was from the storage reservoir. During the following week, however, a total of 33 village water wells became active with gas and at the same time the only old oil well open to the surface also vented gas. The volume of gas from this well increased steadily, to an estimated volume of 1.5 million cubic feet per day in a period of 1 week. Then it began to flow water under sufficient pressure to support a water column approximately 80 feet in height.

As might be expected with the proximity of the Village to the crest of the structure and with the Village well penetrating the Galena formation, gas began to enter the well and in such quantity that the pump became continually gas-locked, cutting off the source of water supply.

EMERGENCY ACTION

One of the first steps taken was to stop gas injection into the reservoir. Crews of men were dispatched to examine each known well in the area for gas and to provide each well with a seal on the casing top with a vent extending high into the atmosphere. The old oil wells also were located, cleaned to their original bottom, and provided with seals and adequate vents.

To serve the Village with a temporary source of water until a new well could be drilled at another location, the Gas Storage Company laid a water line from its water supply at the compressor station to the Village water treatment plant. A tank truck was placed in service to haul water to farm homes where the water supply wells were showing gas. Engineers of the State Department of Public Health surveyed the compressor station water supply to insure that it met requirements as a safe water supply and also advised on procedures that should be followed to insure that the water hauled and delivered to the farm homes was handled in a sanitary manner. The Gas Storage Company also arranged for the drilling of a new well for the Village in the north part of the Village, an area where no migration of gas had been found in the upper formations.

Pending opportunity to make a thorough study of possible causes of the gas leakage, it was believed that, if enough vent wells were drilled, the activity of the migrating gas in the upper formations could be decreased or perhaps even stopped. On this theory, vent wells into the Galena were drilled adjacent to each injection-withdrawal well and allowed to vent to the atmosphere.

GROUND WATER CONTAMINATION

The first analyses of the escaping gas identified it as native to the formation. These tests showed hydrogen sulphide, nitrogen, methane, etc.; however, a short time later, traces of ethane, which is not present in the native gas but comprises about [illegible] percent of the stored gas, were found. Water samples collected from various wells gave no evidence of leakage of waters from other formations up into the Galena. Certain undesirable characteristics of the water (such as presence of hydrogen sulphide and traces of oil) from that formation, however, did become more pronounced. Undoubtedly, the pressures created in the formation by the gas moved the water, oil, and native gas to the water wells in varying mixtures, causing more undesirable characteristics than normally existed.

THEORIES ADVANCED

Several theories were advanced as possible explanations for the migration of gas from the 1750-foot-deep reservoir up to the 150-foot level. They may be summarized as follows:

1. Faulty well cementing. The cement could have channeled between the casing and the bore hole, providing several small avenues of escape at one or more locations.

2. Lack of adequate caprock. The hard dense dolomite immediately overlying the sandstone reservoir could be porous in some areas; this would permit the upward migration of storage gas.

3. Faulting. The upwarping of the strata necessary to produce such a structure could possibly have exceeded the elastic limit of the overlying formations, causing fractures or faulting.

4. Old Well. Approximately 20 old oil test holes have been located. One or more of these test holes could have been drilled to the deeper horizons, possibly into the gas storage reservoir.

SEARCH FOR SOURCE OF LEAKAGE

All the theories were thoroughly explored. Each well was surveyed with gamma ray and neutron logging equipment; five wells were drilled and completed to each formation between the Galena and the Galesville reservoir to sample for leakage gas; 21 shallow structure test holes were drilled to the Galena in areas of steep dip to check the possibility of faulting. None of these tests gave results that indicated the source of gas leakage. Additional tests were made. Sensitive thermistors were used to check each well from top to bottom for temperature variations; down-the-hole microphones were run in each well to ascertain whether there were any extraneous noise levels; and Dowell's Spinner Survey was run on each well to determine any flow variations after the wells were shut in. The latter tests also gave negative results.

The use of a radioactive tracer to locate gas movement behind the well casing was first attempted at Herscher. Argon-41, a radioisotope of argon gas with a half-life of 109 minutes, was used. Cylinders of argon gas were irradiated at Argonne Laboratories and after removal from the reactor were transported immediately to Herscher by car. The irradiated gas was transferred to a cylinder, under 2000-psi pressure, equipped with a time release mechanism. Each well to be tested was plugged back to the casing shoe with roadmix limestone. The cylinder of argon-41 was lowered into the casing until the end of the cylinder was set directly opposite the shoe. The gamma ray instrument was positioned approximately 20 feet above the cylinder to detect the movement of radioactive gas behind the casing. It was discovered that injection and withdrawal of a few linear feet of pipeline gas into and out of the well during testing made it possible to control the radioactive cloud in the casing and maintain it at shoe level. The injection-withdrawal wells were tested twice: at 100 millicuries of intensity and then at 200 millicuries. No evidence of migrating gas was detected.

By December of 1954, observations on the gas collecting in the Galena formation indicated that the vent wells were preventing pressure buildup. Since the gas lost through the vents ranged from 6 to 14 million cubic feet per day, a gathering system was constructed to collect the gas for recycling into the Galesville reservoir.

CONCLUSIONS

Many additional tests have been made during the years since the leakage first occurred in 1953. No conclusive evidence has been developed to prove how gas from the Galesville travels to the Galena; however, the leakage is controlled and the storage project is fulfilling its objective. The zone of contamination appears to be confined above the structure on leased property of the Company. To recompense owners of water wells affected by the leakage gas, the Storage Company has made improvements to the Herscher water system and laid water main extensions to serve many farm homes. Where water mains could not be extended to affected farm homes, new wells were drilled in areas not affected by the gas.

ACKNOWLEDGMENTS

Appreciation is expressed to Mr. O. C. Davis, General Superintendent of Storage for Natural Gas Storage Company of Illinois, and to Mr. C. W. Klassen, Chief Sanitary Engineer of the Illinois Department of Public Health, for their assistance in the preparation of this paper.

TWO CASES OF ORGANIC POLLUTION OF GROUND WATERS

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It is well known that ground waters are subject to pollution by organic materials. It may not be so well known that the investigation of such pollution in ground water is much more difficult than in surface waters. The two cases reported here illustrate these difficulties.

The first incident concerned pollution by pyridine bases, which many people consider to be among the most unpleasantly odorous substances known. The laboratories of the Sanitary Engineering Center were asked to confirm the findings of a State Board of Health, which supplied the samples.

The samples were obtained from shallow wells within a radius of about 300 yards of a plant producing pyridine compounds synthetically as well as from coal tar. The inhabitants of the houses found the water unusable because of the odor, and this was fully understandable when the carboys were opened. A very strong odor of ammonia partially masked the pyridines but on standing faded sufficiently so that the characteristic pyridine odor became unmistakable.

Since the plant had a lagoon on a porous gravel soil and since no other source of pyridines in the vicinity was known, the case seemed rather obvious.

But in pollution cases that may involve court action and in any event call for expenditures of large sums of money, some more tangible evidence than odor recognition is desirable. Colorimetric tests showed pyridine contents of less than 1 ppm in one well, 1 ppm in a second, and 7 ppm in a third, while the plant lagoon showed 5 ppm. Ultraviolet spectra confirmed these results and gave tentative identification of the compounds, pyridine and its monomethyl derivatives, the picolines. Although the colorimetric test is not reliable on mixtures, it was sufficient to show the order of magnitude of the pollution.

Infrared spectroscopy gave positive identification of the isomers present; and a further confirmation was obtained by X-ray diffraction studies of the chloroplatinate derivatives, although a great deal of difficulty was encountered in removing the ammonia, which also gives a chloroplatinate. Another analytical difficulty was the heavy loss incurred in evaporating down the carbon disulfide solution obtained on extracting the pyridines from the aqueous sample for infrared examination. Although it would appear easy to evaporate off a solvent boiling at 46° from pyridines boiling upward from 115°C, it was not and heavy losses were incurred in the final concentration steps. Such conditions are ideal for gas chromatography; unfortunately, a suitable instrument was not available at the time.

The most interesting point about the results of the analytical work was that the most heavily contaminated well showed largely gamma-picoline with a much smaller amount of the alpha isomer. The lagoon, on the other hand, contained principally alpha- and beta-picolines in roughly equal proportions.

Several possibilities presented themselves. In the time required for leakage from the lagoon to reach the wells, there might have been large changes in the composition of the lagoon. That is, if it was the leakage from the lagoon that actually reached the wells, it might have taken months and no information on routes of ground water or rates of travel was available. The composition of the contaminants found in the wells, therefore, would have to be compared with the lagoon as it was estimated to have been at some time in the past, and a number of assumptions would have to be made about relative stabilities of the isomers and relative rates of travel.

This point was of great interest because the reasoning behind the investigation was that a good case would be obtained if it could be shown that the same components were present in the well as in the most suspect source of contamination, and even better if it could be shown that these components were present in similar concentrations.

In the absence of a positive connection between the lagoon and the wells, there was left only a strong probability. Other possibilities, of course, would be leakage or discharge from another point in the plant or conceivably even from some quite distant source.

The weight of evidence was undoubted, but it was by no means as clear cut as in an investigation of pollution of surface water; and, if there had been an alternative source for the pyridines, there would have been no case at all. In a similar case involving surface waters, it would have been fairly easy to sample above and below the plant and in the vicinity of the intake for the house and get definitive evidence concerning the source and travel of the pollutant.

The second case had to do with suspected pollution by hydrocarbons and was of particular interest because the obvious explanation turned out to be the wrong one.

A farmer claimed that fuel oil had leaked out of nearby storage tanks into the ground water and had contaminated his well. The contaminated well was in an isolated rural location, miles from any visible source of pollution, yet the storage tanks had been inspected and pronounced tight.

Activated carbon from a filter at the site was extracted with chloroform. The extract was separated into acidic, basic, and neutral fractions by solvent separation, and the neutral fraction was chromatographed on silica gel.

It was found that most of the odor, which was described as "paint like," appeared in the neutral fraction. The fraction from chromatography containing the oxygenated compounds was found to be responsible for most of this odor, whereas the fraction containing almost pure aliphatic hydrocarbons was quite similar to a white mineral oil and had practically no odor. In addition the "aliphatic" fraction constituted less than 30 percent of the neutral fraction, which itself constituted only 45 percent of the whole raw chloroform extract. Thus the aliphatic hydrocarbons constituted less than 14 percent of the total extract obtained from the carbon filter by use of a solvent that experience had shown removes such substances almost quantitatively.

These results were not at all what would be expected for fuel oil pollution. Fuel oil would give a substantial yield of aliphatic compounds of the kerosene type in addition to the mineral oil. Experience has shown that oxidized hydrocarbons are more fragile biologically than the parent material, so that only very small amounts of oxygenated substances would be expected.

The infrared spectra of the fractions that had considerable odor all indicated large amounts of highly oxygenated substances, very similar to corresponding fractions from rivers carrying mixed domestic and industrial pollution in varying stages of oxidation. It was impossible to draw really firm conclusions, but the most likely explanation was that the ground water had not been contaminated by the nearby oil tank, but by some distant source, such as a large river, or by a local source not related to the stored oil.

Our knowledge of what goes on in the way of bacterial action in these underground streams, and of adsorption processes on clay soils, etc, is very meager. The travel of pollution through underground strata is clearly not to be defined unequivocally without relatively large expense. The examples cited illustrate the difficulty of reaching firm conclusions concerning the nature and source of ground water pollution on the basis of a few "grab" samples.

CONTAMINATION BY PROCESSED PETROLEUM PRODUCTS

Lynn M. Miller, Consulting Engineer

Ground water contamination resulting from poor disposal practices, leaking storage tanks or pipelines, and accidental spills of petroleum products have been experienced throughout the country. Until rather recent years little attention was given to disposal practices that have resulted in some of the most critical contamination cases of record. Worthy of note is the paradox in attitudes between the times when an interest is accused of contributing to petrochemical contamination and when the cost of the losses is evaluated. This is not to infer that all cases represent malicious acts. Many instances are related to true accidents, and just as many, or more, can be related to negligence.

SPECIFIC CASES

A brief resume of a few reports received from throughout the country will serve to illustrate the average type of problem.

Tanks and Pipelines

Reports of private and public water supply wells contaminated by gasoline and oil that has escaped from buried pipelines and above- or below-surface storage tanks are very numerous. Among those states reporting the greatest frequency of such incidents are Colorado, Georgia, Maryland, Michigan Nebraska, New York, North Carolina, and Ohio.

Some of the incidents are amusing even if pathetic. One case in northwestern Ohio will serve to illustrate this point. The owner of a home under construction ordered a fuel oil delivery to permit furnace operation for plaster and paint drying. The oil delivery was made but the furnace would not operate. Of course some controversy developed when it was determined that the tank was still empty; however, that difference of opinion was minor when compared to the furor that developed when it was determined that over 200 gallons of fuel oil had been dumped into the new water well in the front yard. A similar case was reported for an area in central Michigan.

Gasoline has been reported to have traveled nearly 2 miles from a leaking tank. Many filling stations and bulk stations have discovered, or have had discovered for them, that leaking tanks mean reduced profits. Odd odors not generally related to refined petroleum make the detection of some contaminants somewhat more difficult. Skunk-like odors lead one far astray in a preliminary investigation.

True Accidents

In the realm of true accidents are such incidents as overturned tank trucks and broken containers. The common procedure in cleanup is to flush the area with water to avert fire hazards. Several private and some public wells have eventually shown the consequences of such action. In one case a municipal storm sewer conducted the water-borne gasoline to an abandoned gravel pit from which the fluid migrated to private wells.

Of more widespread consequence are the accidental spills, or other losses, in areas where fractured rock materials close to the surface are the major aquifer. Travel is rapid and for great distances in most such areas. Georgia, Kentucky and Minnesota, among other states, have experienced such problems.

Negligent Acts

Little or no thought seems to have been given to disposal practices in some instances. During the course of a preliminary ground water investigation, in a small Michigan city, an abandoned city well was uncapped to determine its usefulness as an observation well. The apparently high static level would permit pumping with a gasoline-engine-driven ditch pump. When this was attempted, the pump operator, who is the water works superintendent, was severly burned about the head and arms in an explosion and fire. Investigation revealed that at one time several wells in the area had been pumped through a common suction manifold that terminated in a building. When new larger wells and a new pumping station had been constructed, the old building had been converted to a garage and maintenance center with a floor drain that discharged into the old suction manifold. Several feet of inflammable fluid mixture was removed from the water surface in three of the five wells in the group. Fortunately, neither drawdown interference nor the volume of volatile fluid had been great enough to allow migration into the aquifer and cause actual contamination of the city water supply. If such contamination had occurred, location of its source would have been very difficult. Even with the evidence at hand, the municipal administrators were difficult to convince.

Improper Disposal

Many incidents of contamination resulting from waste dumping into pits or upon the surface in highly permeable sands or gravels have been reported. Some of these have required the abandonment of private wells and great personal hardship when deeper aquifers could not be located.

Some municipal water works administrators appear either reluctant or negligent in matters of policing activities that may affect their ground water supplies. In a Massachusetts community waste liquor from the manufacture of insecticides was disposed of into a sump only 500 feet from a gravel well of moderate depth. The resulting phenolic contamination brought about only a relocation of the dumping site, and continual policing to prevent a reoccurrence of the problem was required.

Spent diatomite from filters used to reclaim dry-cleaning fluids was dumped onto the ground surface behind a dry-cleaning establishment in one community of another state. The practice probably was observed but not condemned until contamination of the municipal wells located only 250 to 300 feet away and about 40 feet deep was detected. In this instance, the ground materials were known to be sand and gravel and the wells were located to take advantage of infiltration from a surface water source. The natural ground water flow was toward the wells and a lake.

Those cases where an industry has been shown to be the likely source of contamination are usually the most publicized. One case in Michigan involved the appearance of phenols in two city wells that were widely separated. In the search for the source, considerable thought was given to oil refinery operations located within the town, but remote from the well sites. It was shown, however, after collection of many well logs, construction of geologic cross sections, and analysis of extensive pumping test data, that a refinery waste disposal area was the source area. The specific source was a combination burning and infiltration pit. The pit was replaced with a brick-lined steel tank; however, collection and interpretation of the necessary data required a considerable expenditure of municipal and governmental agency funds. Fortunately, some of the data were applicable to other studies.

Where materials are dumped onto the ground, normal observation should detect the potential danger to ground waters. It is when, under the guise of "good citizenship," fluids are injected into the ground that detection may be delayed until actual damage has occurred. When a well is drilled for the specific purpose of waste disposal, many people are usually aware of its purpose and statutes can be used to regulate the drilling activity. Too many old wells, no longer fit for supply uses, have been and are available for indiscriminate use as disposal wells.

SUMMARY

Ground water contamination by petroleum products is not unique to any type of locality or geographic region; cases have been reported from Alaska to Florida and from most points in between. The frequency of reports appears to be related to the density of population and to activities, as is most any type of contamination.

There is a definite need for increased vigilance, and in many areas statutory control, to detect the mishandling or improper disposal of petroleum products. The technological advances made in producing more usable products from petroleum provide an ever-increasing variety of opportunities for this type of contamination to occur.

THE MOVEMENT OF SALINE GROUND WATER IN THE VICINITY OF DERBY, COLORADO*

L. R. Petri, U. S. Geological Survey

Derby is about 3 miles north of the city limits of Denver and borders on the western edge of the Rocky Mountain Arsenal, an Army Chemical Corps installation. In the spring of 1954 some farmers living near Derby, between the arsenal and the South Platte River, complained that use of ground water resulted in severe damage to crops. In the fall of 1954 the U. S. Geological Survey, at the request of the Chemical Corps, studied briefly water quality conditions on the arsenal property and in a few wells in the neighboring farmland. Results of this study indicated the presence of a body of highly saline ground water on the arsenal property. In 1955 and 1956 a detailed hydrologic investigation in an area of about 70 square miles in the vicinity of Derby, including the nearly 28 square miles of arsenal property, was made by the author and Mr. Rex O. Smith, a geologist of the Survey. One of the objectives of this investigation was to determine the manner in which water from the highly saline body moved through the area.

In the fall of 1955 the body of highly saline ground water underlay about 4-1/2 square miles, of which all but about 1/4 square mile was within the confines of the arsenal. (See Figure 1, area in which chloride content exceeded 1,000 ppm.) The arsenal disposal ponds, into which liquid wastes had been discharged since 1943, directly overlay the body of highly saline ground water. Because the ponds had highly permeable beds, the liquid wastes percolated readily to the ground water reservoir. The liquid wastes and the water from the shallow wells within the 4-1/2 square miles had similar composition; in October 1955 both had about 9,000 ppm of dissolved solids, which consisted mostly of sodium and chloride ions. Water from one well had 10,600 ppm of dissolved solids of which 5,730 ppm were chloride.

The chloride content of the water underlying the farmland from the arsenal to the river probably was less than 100 ppm prior

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*Publication authorized by the Director, U. S. Geological Survey.

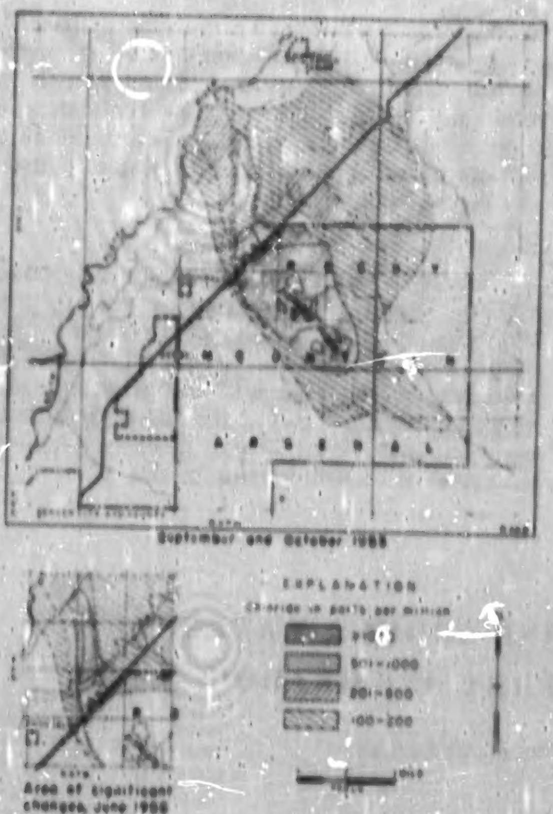

A R S E N A L
September and October 1955
EXPLANATION
Chloride in parts per million
501-1000
201-500
100-200
Area of significant changes, June 1956

FIGURE 1. AREAL DISTRIBUTION OF CHLORIDE IN GROUND WATER IN DERBY, COLORADO, AREA IN SEPTEMBER AND OCTOBER 1955

to intrusion by the saline water. The movement of the saline water, therefore, could be determined by the amount of increase in the chloride content of the water underlying the farmland.

After percolating to the ground water reservoir, the saline water, following the general direction of ground water movement across the arsenal, moved northwestward to the South Platte River Valley. The configuration of the bedrock channeled most of the flow, from the highly saline body, into the valley through a narrow gap near the northwest corner of the arsenal. After entering the valley, the saline water, influenced by the main flow of ground water moving down the valley, changed to a more northerly course and flowed in a fairly narrow zone to the river.

During the investigation the chemical quality of the ground water was determined several times, and each time the chloride content of the water from most wells in the narrow zone increased significantly. From 1955 to 1956 the chloride content of the water in much of the zone nearly doubled. Where the chloride content had been 500 to 1000 ppm in 1955, it was 1000 to 2000 in 1956. (See small map on Figure 1.) Unusual fluctuations in chloride content, some more than 200 percent, were detected in water from some wells along the edge of the zone, and the fluctuations seemed to be closely related to the rate and frequency of pumping. When pumping was heavy, the chloride content increased; and when pumping was light, the chloride content decreased.

Moving downgradient through the zone, the saline water changed from a sodium chloride type to a calcium chloride type. On either side of the zone, water unaffected by the saline intrusion contained predominantly calcium and bicarbonate ions.

The approximate rate of ground water movement in the valley fill northwest of the arsenal, as indicated by field and laboratory tests, was about 13 feet per day, or about 4800 feet per year. Although the hydraulic gradient in the uplands on the arsenal grounds is greater than that in the valley fill northwest of the arsenal, the rate of movement in the uplands probably is less because the permeability of the water-bearing material is less.

Although percolation of the liquid wastes to the ground water reservoir began in 1943, several years undoubtedly elapsed before any of the saline water reached the farmland in the valley. The amount that reached the farmland during the next several years probably was small enough that dilution with better quality ground water in the valley allowed the intrusion of the saline water to go unnoticed. It is understandable why the intrusion was especially apparent in 1954, because during 1954 the annual precipitation was only 7-1/2 inches, which is about half the normal amount. Irrigation wells were pumped heavily, some almost continuously, during the growing season.

Shortly after this investigation was made, the disposal ponds were lined to prevent further percolation of the liquid wastes to the ground water reservoir. The amount of wastes that had already entered the reservoir was so great and the movement of the ground water so slow that the effects of the saline water on the quality of the water in the farmland was likely to continue for many years.

PUBLIC HEALTH ASPECTS OF THE CONTAMINATION OF GROUND WATER IN THE VICINITY OF DERBY, COLORADO

G. Walton, Sanitary Engineering Center

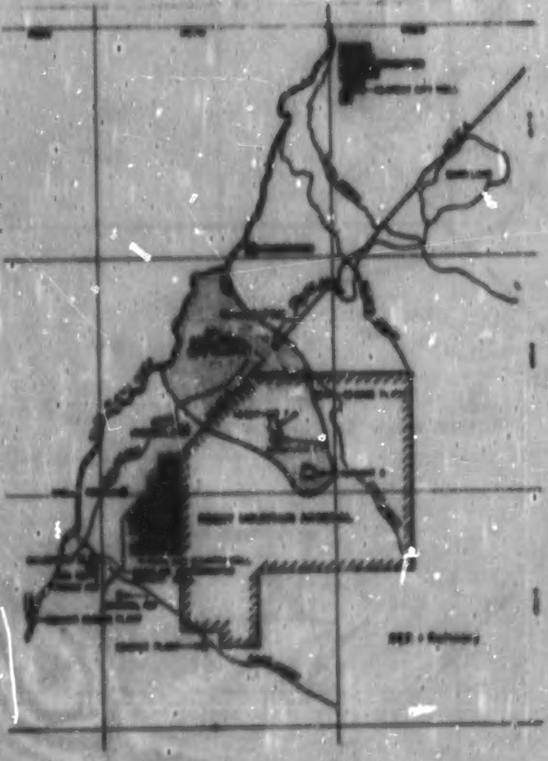


FIGURE 1. DERBY, COLORADO, AREA INVESTIGATED IN CONNECTION WITH CONTAMINATION OF SHALLOW GROUND WATER

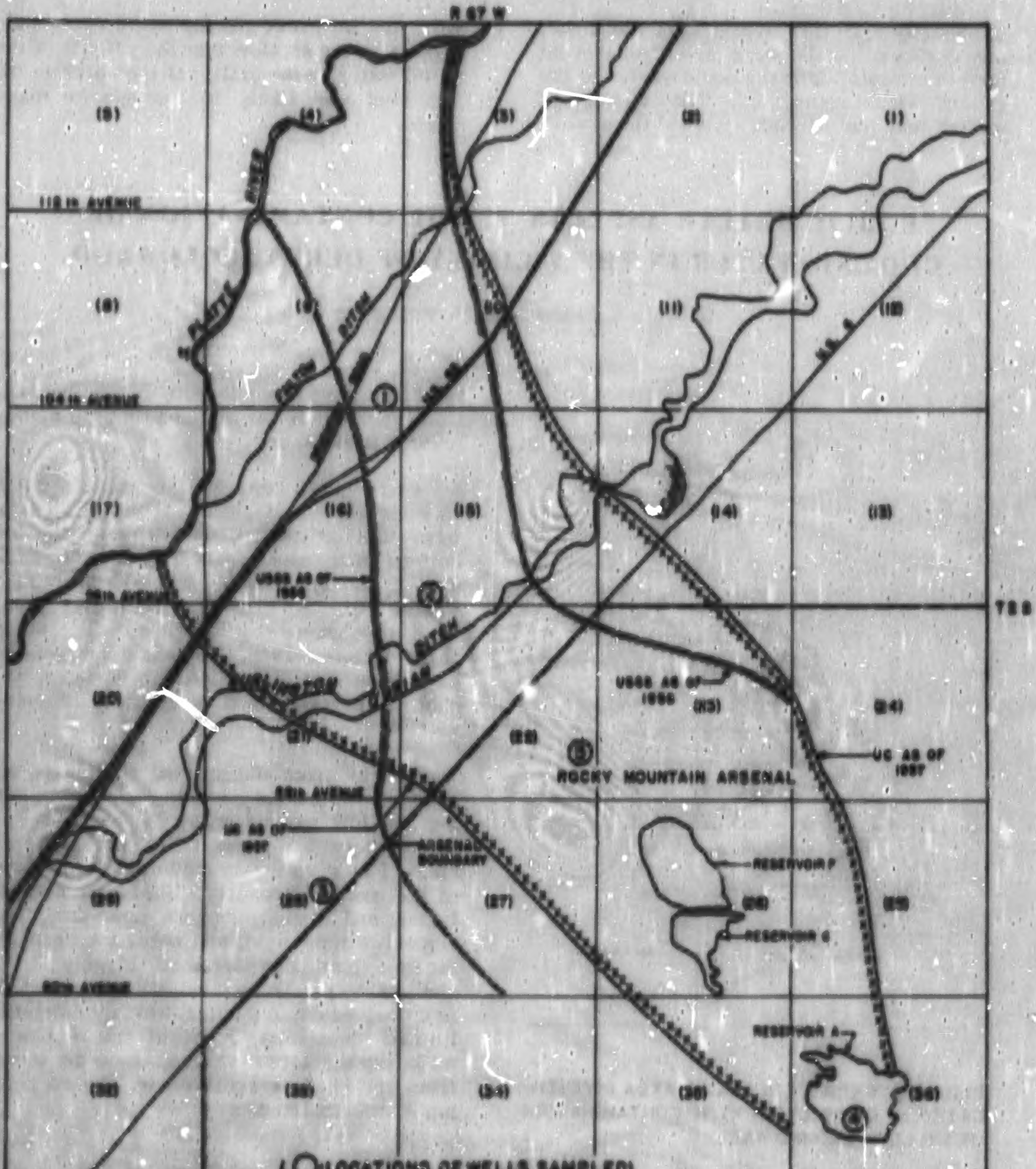
The Rocky Mountain Arsenal is located just northeast of Denver, Colorado (Figure 1). Started in 1943, the arsenal was operated by the Chemical Corps for several years for the production of chemical warfare agents. More recently, the industrial facilities have been leased to the Shell Oil Company, which has utilized them to manufacture insecticides.

From 1943 through September 1955 wastes from various chemical processes were discharged to Reservoir A (the locations of the reservoirs are shown in Figures 1 and 2). During part of that period wastes from the chlorine-processing plant were discharged to Reservoir C. Since early October 1955, all industrial wastes have been discharged into the 96-acre, asphalt-membrane-lined, evaporation Reservoir F.

Wastes from the unlined holding ponds have seeped into the ground and contaminated the shallow ground water throughout approximately 5 square miles of the South Platte River valley immediately northwest of the arsenal property. This is an area of farms and some suburban housing. The region is semi-arid, and water for crop irrigation has been obtained largely from shallow wells. A second source of water is a deep artesian aquifer, which yields only limited quantities. Most of the domestic wells tap the latter source, since the water from the shallow aquifer has always been highly mineralized.

HISTORY OF CONTAMINATION

The first indication that the ground water had become contaminated was damage to crops irrigated with water from shallow wells. Such crop damage was observed at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112th AVENUE
104th AVENUE
78th AVENUE
88th AVENUE
80th AVENUE
S. PLATTE RIVER
COLTON DITCH
BURLINGTON DITCH
U.S. 85
U.S. 6
USGS AS OF 1956
UC AS OF 1957
ARSENAL BOUNDARY
ROCKY MOUNTAIN ARSENAL
RESERVOIR F
RESERVOIR C
RESERVOIR A
①
②
③
④
⑤
(○ LOCATIONS OF WELLS SAMPLED)

Boundary of contaminated area as indicated by 200mg/l isochloride concentration, 1956, USGS Report
Boundary of contaminated area as indicated by Phytotoxic characteristics, 1957, Univ of Colorado Studies

FIGURE 2. SOUTH PLATTE RIVER BASIN, COLORADO — SUSPECTED AREAS OF SHALLOW GROUND WATER CONTAMINATION SHOWN AS OF 1956 AND 1957

the Newson farm in 1951, at the Powers and Munson farms in 1952, and at the Yamamoto and Miller farms in 1953.

Complaints and subsequent claims for damages led to the Chemical Corps' engaging a firm of consulting engineers to investigate the problem. Their report recommended and resulted in a substantial reduction in the volume of wastes and, starting in October 1955, the retention of all wastes in Reservoir F. Another result was a contract with the University of Colorado to undertake plant bioassay, chemical, and geological studies to determine the identity and source of any contaminants causing crop damage. These and other studies emphasized the effect of the contaminated water on agricultural uses. It was not until 1959, when the State of Colorado requested that the Public Health Service make a reconnaissance survey, that serious concern developed over the use of such waters for domestic purposes.

PUBLIC HEALTH STUDY

At the time of the Public Health Service survey, contaminants known to have been present in certain shallow well waters taken from within the area included chlorides and chlorates. The weedicide 2,4-D was known to have been isolated from wastes in the holding pond, and plant bioassay studies had indicated that it or other phytotoxic organic substances had been present in some of the shallow well waters. Still other contaminants known to have been in wastes discharged from the arsenal's operations were salts of phosphonic acid, fluorides, and arsenic.

During August 1959, visits to 50 of some 150 homes in the area provided data on 23 domestic water supplies. Eighteen were deep well supplies, which were reported satisfactory wherever a member of the household could be interviewed. Five dwellings were served by shallow wells. Waters from such wells were used for drinking and for culinary purposes at three residences, at two of which the water was reported to have had taste and odor.

Previous studies by the U. S. Geological Survey (1) and the University of Colorado (2) had established the general area of shallow ground water contamination. The isochloride line for the 200-mg/1 concentration as of June 1956 is shown in Figure 2. Since shallow ground waters from this area normally contain not more than 100 mg/1 of chloride, the 200-mg/1 concentration is evidence that at least 3 to 5 percent of the water within the area originated from the highly contaminated ground water underlying the arsenal property. Also shown in Figure 2 are boundaries of the area throughout which the shallow well waters had exhibited phytotoxic characteristics, as determined by the University of Colorado studies through 1957.

Among the recommendations made in the report on this study (3) were that steps be taken immediately to determine present boundaries of the area in which the shallow ground water had become contaminated, to analyze all domestic water supplies from wells within that area, and to provide written notice to the owners of contaminated wells that the water is "unsafe for drinking or culinary uses." Chloride concentrations in excess of 200 mg/1 were to be considered as evidence of contamination until more adequate information could be developed concerning the contaminants present and their concentrations. Other recommendations provided for a monitoring program, toxicological studies to better establish safe permissible limits of certain contaminants in potable water, and an investigation of the sludge accumulation in Reservoir A.

Subsequent activities of the Public Health Service have been limited to analyses of five well water samples collected between October 29 and November 3, 1959 (4), a study of the toxicity of chlorates, and consultation services to the Colorado State Department of Health.

Table 1 summarizes the results of the analyses of the well waters. Figure 2 shows that Well No. 3 is adjacent to, but outside, the area influenced by seepage from the ponds receiving wastes from operations at the Rocky Mountain Arsenal. All other wells are within the area contaminated. Although such contaminants as chlorates, phosphonates, and 2,4-D were, if present, well within the tentative permissible limits recommended for drinking water, other sub-

Table 1. COMPARISON OF ANALYTICAL RESULTS FOR WATERS FROM WELLS IN OR ADJACENT TO CONTAMINATED AREA NEAR DERBY, COLORADO, WITH 1946 PHS DRINKING WATER STANDARDS

(All results except pH in milligrams per liter)

Analysis	1946 PHS Standards	Well number and sampling date				
		No. 3, in uncontaminated area (11/2/59)	No. 4, in bed of reservoir (11/3/59)	No. 5, on Rocky Mtn. Arsenal (11/3/59)	No. 2, irrigation well (10/29/59)	No. 1, in Haseltine area (10/29/59)
Solids						
Total	1,000[a]	493	10,000	2,800	3,760	2,620
Volatile		96	965	446	980	808
Hardness (total as $CaCO_3$)		212	1,990	280	924	828
Calcium		85	389	77	389	122
Magnesium	125[b]	0	258	21	0	152
Alkalinity						
Total (as $CaCO_3$)		287	700	827	372	262
Hydroxide (as $CaCO_3$)		0	15	23	0	0
Sulfate (as SO_4)	250[b]	104	3,000	249	435	485
Fluoride	1.5	0.6	4.0	2.8	1.2	1.2
Chloride	250[b]	40	1,410	854	1,229	784
Sodium		81	2,200	880	580	800
Potassium		3.4	12	7.9	5.9	5.0
Phosphate						
Ortho (as PO_4)		0.12	4.5	2.4	0.08	0.16
Poly (as PO_4)		0.04	0.24	0.16	0.22	0.34
Phosphonate (as PO_4)		0.0	0.0	0.1	2.1	0.0
Chlorates (as ClO_3)		< 1	< 1	< 1	< 1	< 1
2,4-D		< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
ABS		0.1	0.7	0.6	0.6	0.4
pH		8.3	8.4	8.6	8.0	8.0

[a] Recommended maximum limit 500 mg/1, permitted 1,000 mg/1.
[b] Recommended maximum limit.

stances - solids, hardness, alkalinity, fluorides, and chlorides - showed that these waters have abnormal characteristics that could only be associated with wastes from the operations at the Arsenal. Exploratory spectrographic analyses also showed the presence of abnormal concentrations of iron, manganese, and molybdenum, which indicated the corrosive characteristics of these waters.

Waters from the four wells were considered unsuitable for domestic water supplies on the basis of the analytical results for the samples submitted. Further consideration of the source of the contamination, the possible nature of the contaminants that might be present, and the history of damage to crops when such water had been used for irrigation required that these waters be rejected as domestic water supplies.

SUBSEQUENT DEVELOPMENTS

Since 1959, the Chemical Corps has hauled water for domestic use of those householders formerly using contaminated well water. It is understood also that provision has been made to facilitate processing of limited claims for damages, such as the expense incurred in drilling a well into the deeper, uncontaminated aquifer.

Both the State Department of Health and the Chemical Corps are monitoring selected wells. Available information reveals no increase in the area with contaminated shallow ground water.

A survey of the industrial waste system has been made and a contract awarded for the construction of a plant to pretreat the wastes prior to their injection into a deep well. All wastes will be discharged to Reservoir F, where chemical nutrients will be added to induce "a complete biological cycle." Subsequent treatment will consist of flocculation, settling, pressure filtration, and disinfection. The clarified liquid will be deoxygenated before injection into the ground.

A contract was let February 2, 1961, for construction of a deep injection well, the plans for which have been approved by the Colorado State Department of Health. This well will be tripled-cased throughout the upper strata and double-cased to a depth of 2,000 feet. The 8-3/8-inch-OD inner casing will extend to a depth of approximately 10,000 feet. Each casing will be cemented in place. Wastes will be injected through a 5-1/2-inch tube extending to the stratum in which they will be discharged. The annular opening between this tube and the casing will be filled with clean water. Since the injection pressure at the well head will be high - up to 2,000 psi, leakage of waste into the annular opening will be detectable by an increase in the reading of a recording pressure gage installed for that purpose.

Consideration also is being given to pumping ground water from wells in the more contaminated areas to waste into the South Platte River. This would be done only at times when the flow of the river provides sufficient dilution to maintain the concentrations of the contaminants within permissible limits.

REFERENCES

1. Petri, Lester R. and Smith, Rex. O., Investigation of the Quality of Ground Water in the Vicinity of Derby, Colorado. Water Quality Division, U. S. Geological Survey, Department of Interior (1956).

2. Bonde, Erick K., Research on Phytotoxic Materials, Contract No. DA-05-021-401-CHL 10,092. Department of Biology, University of Colorado, (May, 1958).

3. Walton, Graham, "Public Health Aspects of the Contamination of Ground Water in the South Platte River Basin in the Vicinity of Henderson, Colorado, August, 1959," Robert A. Taft Sanitary Engineering Center, Public Health Service, DHEW (November 2, 1959).

4. Walton, Graham, "Report on Analyses of Water Samples from Rocky Mountain Arsenal Area, Denver, Colorado." Robert A. Taft Sanitary Engineering Center, Public Health Service, DHEW (April 5, 1960).

DISCUSSION 3

Chairman: R. E. Fuhrman

Mr. Chesler Wilson asked Mr. Robert A. Krieger whether there had been any damage suits, successful or unsuccessful, in connection with brine pollution problems in the Kentucky oil fields. In an unsuccessful case cited, a brine-polluted well developed chloride concentrations as high as 29,000 ppm. The chloride concentration subsequently decreased to about 1800 ppm. A brine injection well was constructed some 300 or 400 feet away, and even though the chloride concentration in the brine-polluted well increased, the suit for damages was lost. Mr. Wilson called attention to the obvious contrast here with cases in the State of Washington where the pollution source could be pinpointed and damage suits prosecuted successfully.

At the invitation of Chairman Fuhrman, Mr. W. W. Hagan of the U. S. Geological Survey, commenting on experience in Kentucky, described the difficulties of proving violation to the satisfaction of the court. He referred to one successful case, however, in which an oil producer who discharged salt water to the ground was fined $500. Although the courts sometimes seem uncooperative, a new oil and gas law, coupled with the work of the water quality personnel of the State, is bringing about continual improvement.

Professor Richard H. Bogan asked Mr. John M. Flynn, Jr., whether he had found any correlation between syndet concentrations and the bacteriological characteristics of well waters. Mr. Flynn stated that his investigations were limited primarily to chemical analyses for ABS and nitrogen cycle constituents. Nevertheless, he did report that ground water close to the surface shows greater amounts of ABS and free ammonia, and is likely to show the presence of coliforms. Toward central portions of the county (Suffolk County, New York), where depth to ground water is greater, ABS and ammonia occur in lesser amounts and nitrates in greater amounts, but coliform organisms are found rarely. These observations were suggestive of work done by Dr. M. Starr Nichols and Elaine Koepp, reported in the March issue of the AWWA Journal. They found in Wisconsin that the percentage of coliform positive samples in water containing 3 to 10 mg/1 ABS was about five times that in water containing no ABS.

Professor Bogan then referred to a situation at Tieton, Washington, where ground water travel rates were apparently unusually high. He asked for comments from Mr. John F. Honstead of the General Electric Company on rapid ground water travel in the same general area. Mr. Honstead reported rates of ground water movement, as indicated by a fluorecein dye tracer, on the order of hundreds of feet per day in extremely permeable formations similar to those reported by Professor Bogan in his paper.

Mr. John E. Vogt was asked by Dr. Graham Walton whether conditions that caused the hepatitis outbreak at Posen were of long standing. Belief was expressed that the conditions had existed for several years before the right combination of circumstances produced the outbreak. Medical persons believe that an unrecognized outbreak of infectious hepatitis had occurred previously at Posen. This is indicated by the apparent immunity of the elderly people in the community, since practically all cases in the recent outbreak involved the younger people.

In response to a question about the source of contamination, Mr. Vogt emphasized that this hepatitis outbreak exploded in three homes served by two wells, both located very close to a septic tank serving a home with a case definitely diagnosed as hepatitis. It is his belief that the home with the infectious hepatitis case discharged the virus, which found its way through the sewage disposal system and soil to the two wells, one 6 feet from the tile disposal field and the other 10 feet from the field. He concluded that the source of virus in the 16 cases was pretty well identified with the initial case of diagnosed hepatitis and further that the virus traced a path through the septic tank, the tile fields, and the thin mantle of drift overlying the rock, and percolated down to the limestone below.

Mr. George Maxey of the Illinois State Geological Survey, a past hepatitis victim, called attention to the incubation period on the order of 20-60 days and asked if the timing between the first case and the subsequent cases agreed with this. Mr. Vogt noted that the incubation period mentioned by Mr. Maxey is the same as that advised by physicians associated with the Posen outbreak. He also indicated that the 15 additional cases of hepatitis followed the first one within 30 days. The virus of hepatitis was not isolated from any of the water samples. (At present the use of human volunteers offers the only means of detecting the presence of infectious hepatitis virus in water.)

Mr. Norman Tuckett of the Broward County Health Department, Florida, addressed a question to Mr. L. Weaver concerning contamination resulting from leaching from sanitary landfills. After indicating that the Broward County Health Department (Florida) proposes to make periodic analyses of public well waters, he asked what particular chemical analyses would be most advantageous for the detection of leaching from garbage, ash pits, and landfills. In reply, Mr. Weaver recommended adherence to already established routine water analyses rather than concentration on specific factors, such as hardness, ammonia content, etc. In emphasizing that the Florida wells of concern have great monthly changes in hardness and alkalinity, caused by variations in rainfall, Mr. Tuckett asked whether metals therefore would be a better indicator. Mr. Weaver, although still favoring the normal water quality analyses, answered that perhaps, as a result of specific study, additional analyses might be advisable.

In reference to Mr. Weaver's suggestion that precipitation in itself is not sufficient to provide the supersaturation requisite to groundwater contamination by leaching, Mr. James E. Hackett, Illinois State Geological Survey, asked if sanitary landfills can be operated safely in abandoned quarries or gravel pits. Mr. Weaver stated that if a sanitary landfill were operated in an area of extremely heavy rainfall and the fill were not constructed to provide proper drainage, difficulties would arise.

Referring to the Rocky Mountain Arsenal problem, Mr. Meyer Kramsky, California Department of Water Resources, asked whether Dr. Walton had any data on the cost or capacity of the 10,000-foot-deep injection well. Although stating that he had no specific data, Dr. Walton said he understood that the well may cost more than $1,000,000 and that it is hoped up to 400 gpm can be injected.

Mr. Wallace de Laguna, Oak Ridge National Laboratory, referred to a recent magazine article, which stated that when the question of water contamination at the Rocky Mountain Arsenal first came up the Army stated that its activities were classified and refused to discuss the matter.

He asked either Mr. Lester R. Petri or Dr. Walton whether this uncooperative attitude was reported correctly. Dr. Walton stated that in 1959 when he conducted a survey in the area the Chemical Corps cooperated fully and that the information provided was cleared in a meeting with the Corps in Washington and later presented at a public meeting in Denver.

Referring to the presentation by Mr. Frank L. Woodward, Mr. Ralph H. Baker, Jr., indicated his astonishment at the number of private individual wells associated with septic tank disposal of sewage and asked whether the mass housing program involved was financed primarily by FHA. Mr. Woodward then read parts of his paper, "Ground Water Contamination in the Minneapolis and St. Paul Suburbs," for which reading time had not been available earlier. Mr. Martin G. Dretel, D & S Pump & Supply Company, Brewster, New York, asked Mr. Woodward whether it is true that in the Minneapolis-St. Paul area many of the central water supplies would fail to meet the nitrate-nitrogen concentration requirement imposed on individual water supplies. He noted that trade publications have indicated that several cities in Minnesota use water supplies that contain more than 1 ppm nitrate-nitrogen, whereas such nitrate-nitrogen concentrations were not permitted in the waters from privately owned wells. The drilling industry believes that there is undue stress on this point and that individual well supplies are controlled more rigidly than central water supplies. Mr. Woodward acknowledged that in Minnesota there are many public water supplies that contain more than 1 ppm nitrate-nitrogen. In such cases, however, no association of the nitrate with sewage contamination has been demonstrated. It is not believed that 2 or 3 ppm will cause illness. In the late 40's when 138 cases, of which 14 were fatal, were investigated, the lowest concentration that caused illness, diagnosed as methemoglobinemia, was about 35 ppm. People who prepared infant's formula were advised that water could be used safely if the nitrate-nitrogen concentration did not exceed 10 ppm. In the suburban area under consideration the natural water has a nitrate-nitrogen content of less than 1 ppm. Moreover, it doesn't matter much whether 1, 5, or 10 ppm nitrate-nitrogen is used as an indicator, since any of these amounts combined with other pollution indicators will show that some 25 percent of the wells with these amounts of nitrate-nitrogen are contaminated.

SESSION 4

REGULATIONS AND THEIR ADMINISTRATION

Chairman: Murray Stein

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LEGAL PROBLEMS OF GROUND WATER CONTAMINATION

S. Wilson, Conservation Consultant

The dedicated and hard-working people in the United States Public Health Service and all the state and local agencies concerned are well aware of the need for study of the legal as well as the practical aspects of the ground water contamination problem. As public administrators and technicians they know that wherever any job is to be done or authority exercised by public agencies it must be provided for by law. They have learned that whenever an administrator or technician runs into a problem and starts planning action one of his first moves should be to consult his legal adviser, look into the applicable statutes, and if they are inadequate in any respect, seek the enactment of new measures. Unless that is done promptly, important programs or projects may be delayed. So we are now taking a little time in the midst of this Symposium to consider where we stand in the way of legal authority for dealing with ground water contamination and what new legislation is needed for the advancement of an effective program.

This gathering of especially concerned people from all parts of the country testifies to the fact that ground water contamination presents many difficult and urgent problems quite different from those of surface water. Solutions for these problems must be found if the major objective of conserving enough water to meet future population needs is to be attained. The whole pollution control program for both surface water and ground water must move forward, or there simply will not be enough water to go around.

GROUND WATER CONTAMINATION SITUATION

One thing stands out in all the reports on the subject--we are up against another crisis resulting from man's perversity in breaking the laws of nature. We should know from experience that this cannot be done with impunity.

The breach of nature's regulations with which we are concerned consists of the age-old practice of civilized man of disposing of the excreta and remains of his own species and other animals by deposit or burial underground. In a state of nature, such things were left on the surface to be consumed by other forms of life or to disintegrate rapidly under the impact of air, sunshine, and other forces. The processes of consumption and disintegration are much slower underground, with the result that the progressive accumulation of pollution substances below the surface will continue as long as the practice of the underground disposal of waste matter continues.

Effects of Contamination

Nature is more or less tolerant, but she has her limits. There are unmistakable signs that these limits have been passed and that she is already cracking down on the offenders. Among the most ominous instances are those disclosed by recent reports of the painful consequences of ground water contamination from laundry waste in Long Island, New York, the pollution of domestic wells from septic tanks in the suburbs of St. Paul, and Minneapolis, Minnesota, contraction of infectious hepatitis from contaminated well water in Posen, Michigan, and widespread crop damage in the South Platte River Basin in Colorado from chemicals that got into irrigation water through careless disposal of industrial waste. Many other cases of disease and other damage from contaminated ground water are recorded in the published task group reports of the American Water Works Association, and still more are being reported at this Symposium.

All this evidence demonstrates beyond question that many people in different parts of the country are already paying severe penalties for their own or someone else's misdeeds that resulted in ground water contamination, and many more will suffer likewise for a long time to come until adequate counteracting measures can be applied. The situation is bound to get worse before it can get better.

A great many people, including some public officials, seem to be blissfully unaware of the menace of ground water contamination and are doing little or nothing about it. The practice of sweeping the dirt under the rug continues unabated in many parts of the country. Once people get the stuff underground, they think they can safely forget it.

It is true that in sparsely populated areas cases of serious trouble from ground water contamination are not yet numerous or acute. The reports show, however, that the discharge into the ground of sewage, detergents, or other chemical compounds with large quantities of water can build up an actual or potential contamination hazard in a large area in a comparatively short time. It is safe to say that there is no state in the Union where such hazards do not already exist to some extent. These danger spots will inevitably increase in number and spread in extent with the growth of population and the expansion of residential and industrial developments. The handwriting on the wall behooves the responsible agencies at all levels of government throughout the country to heed it.

LEGAL ACTION PROGRAM

Some special factors that affect ground water contamination and must be reckoned with in the development of a legal program are:

1. The sources and accumulations of ground water contamination are myriad and widely scattered. Contamination will spread from these sources for a long time through percolation from natural or artificial sources.
2. In many cases it is difficult or impossible to trace the source or the spread of underground contamination.
3. Protected from air, sunlight, and other forces, underground contamination, both chemical and biological, persists in dangerous form much longer than surface pollution.
4. Surface pollution is usually open and notorious, whereas underground contamination is hidden, insidious, and difficult to get at.

Of course wells and springs fed by contaminated water are the chief means of injury of human beings, livestock, industry, agriculture, and other interests. The common belief in the purity of well water and spring water has been rudely shattered by recent revelations. Except in areas known to be free from underground contamination, it is no longer safe to drink such water without testing or treatment.

Legal measures relating to ground water contamination must be geared to a program of action to:

1. Prevent disease and other harmful effects from the use of contaminated ground water.
2. Prevent further contamination of ground water.
3. Remedy or control existing underground contamination.

In consequence of the multiplicity of sources and the complexity of the affecting factors outlined, ground water contamination is beset by unusual and difficult problems for which conventional measures used on surface water pollution would be largely ineffective. In order to attain the declared objectives, measures especially designed to cope with the peculiar problems of the underground must be employed and special legal provisions adequate to authorize the execution of such measures must be devised, if not already on the statute books.

The laws required for operation of the general water pollution control program were discussed fully at the Washington conference(1). These discussions should be noted so far as they may be applicable to ground water problems. Further discussion here will be addressed to the specific measures needed for dealing with ground water contamination.

Prevention of Harm from Existing Contamination

Clearly the most urgent need for action is in preventing harm from existing underground contamination. Regulations are necessary that will stop the use of water from any source found to be contaminated or in imminent danger of contamination. Action would include publication and posting of warnings, the promulgation of restrictive regulations, and the sealing of wells, or other necessary safe guards. Control of the location and drilling of wells, to insure freedom from contamination, also is necessary.

A legal action program would require extensive and intensive surveys to locate sources of contamination and affected wells and springs. Appropriate regulations would have to be framed and adopted to provide for sampling and testing water and for submission of plans and issuance of permits for the location and drilling of wells under specifications to prevent contamination. The program also would include provisions for continuous inspection to insure compliance with all requirements.

Prevention of Further Contamination

The saying that an ounce of prevention is worth a pound of cure goes double for underground contamination, because it is so difficult to remedy. A polluted surface stream recovers quickly after the source of pollution is abated or controlled. On the other hand, underground contamination works its way into inaccessible places and its harmful properties persist for a long time. In most cases it is extremely difficult if not impossible to remedy or neutralize once established. Hence, it is of the utmost importance to exercise strict control over the location, construction, and use of septic tanks, cesspools, disposal wells, and all other means for disposing of sewage or waste into the ground, as well as over the placing on the surface and use of all accumulations of liquid or solid materials containing contaminating substances that may permeate the ground. These measures must extend, of course, to existing installations or situations as well as to new ones.

Similar control must be exercised over operations for recharge of underground aquifers, underground storage of gas or other substances, blasting or excavation in permeable underground formations, and other operations that may be the means of introducing or facilitating the spread of underground contamination.

For these purposes legal and administrative machinery similar to that for existing contamination will be required along with provisions for the issuance of orders and the application of other enforcement measures customarily employed in water pollution.

Action Against Existing Contamination

The introduction into the ground of further contamination from existing sources as well as from new sources can and should be stopped by the measures already outlined. Steps also should be taken for the elimination or neutralization of existing accumulations of underground contamination, as far as possible.

Where responsibility can be fixed upon municipalities, industries, or private individuals, these groups or individuals should be required to undertake the necessary remedial operations, wherever feasible, or to pay appropriate compensation in lieu thereof so far as liability can be legally enforced.

This procedure would be in the nature of legal action to compel abatement of a public nuisance or payment of damages. This remedy might not be workable on past cases because of statutes of limitations or other legal obstacles except so far as existing provisions of the pollution control laws authorize procedures that may be applicable to underground contamination. It would be desirable to augment the present statutes, as far as necessary, by special provisions dealing with underground contamination.

For cases where it is not possible to compel remedial action by a municipality or a private corporation or individual and where the accumulation of underground contamination is serious enough to warrant action in the public interest, provision should be made for public agencies to undertake measures to remove or counteract the contamination, as far as feasible. This will require the enactment of statutory provisions authorizing such action and also authorizing entry upon private lands for this purpose where necessary, including authority to condemn the right of entry, if the right of entry is not yielded voluntarily by the landowner.

SUPPLEMENTARY SPECIAL MEASURES

In addition to the measures outlined, certain supplementary measures may be useful for control of ground water contamination.

Prohibition of Pernicious Substances or Practices

It may be necessary in some cases to restrict or prohibit the use of underground disposal for particular contaminants that cannot be successfully treated or controlled or that interferes with treatment processes. It may also be necessary to restrict or prohibit the operation of particular types of establishments or devices that in underground disposal operations discharge excessive amounts of water or other liquids, overloading treatment facilities or accelerating or extending the spread of underground contamination beyond safe limits. Such measures can be applied by appropriate regulations under enabling statutes.

Proof of Safety of New Products

In connection with the preceding suggestions, underground disposal by users of new chemicals or other products capable of permeating the ground but with unknown effects may be restricted or prohibited unless and until the manufacturer or distributor produces satisfactory evidence that the use of the product will not cause underground contamination or interfere with treatment processes. The burden should be on the manufacturers of the new products to have them tested before putting them on the market. This requirement might have a salutary effect in promoting research in furtherance of production of types of detergents, insecticides, and other compounds that would be free from contaminating properties.

Provisions of this kind, of general application and somewhat drastic effect, should preferably be instituted by statute rather than by regulation.

Zoning or Building Regulations

One of the most important long-range activities in the entire program for controlling ground water contamination is the inclusion of adequate provisions, in zoning and building regulations governing the development of real estate for residential, industrial, or other purposes in unsewered areas, for the location, spacing, and construction of all septic tanks and other underground sewage or waste disposal facilities and wells. Installation of such facilities should be prohibited in areas where they cannot be used without causing contamination of ground water or entailing danger of harm.

Cities and villages generally have power to adopt such regulations. Similar authority should be conferred by law on counties, rural towns, sanitary districts, or other governmental units in order to extend control over real estate and industrial developments outside of municipal limits. City or village councils and other local governing bodies are often reluctant to adopt adequate pollution control regulations for fear of interfering with real estate or industrial developments. Hence express statutory provisions should be enacted, empowering a state agency to prescribe effective regulations for any area where local agencies lack or fail to exercise authority.

CONSIDERATIONS OF GENERAL APPLICATION

Certain considerations affecting all measures dealing with underground contamination should be noted.

Basis of Public Authority – The Police Power

Effective control of ground water contamination will require the exercise of public authority in regulating the use of private property to a far greater extent than control of surface water pollution. Hence moves to that end will undoubtedly be resisted and questions will be raised as to the underlying authority for such measures, especially in states that adhere to antiquated common law rules of absolute private ownership of ground water.

There is much diversity among the states, both in statutes and in the rules laid down by the courts, as to the nature of private rights in ground water.

From the few legal decisions involving public authority over ground water and from many decisions involving public authority over other kinds of private property, it is safe to assume that the courts generally will uphold the power of the state in cases involving ground water contamination so far as may be necessary for protection of the public health and welfare, despite the fact that the ground water may be private property.

No doubt it will be contended that contamination of ground water by an individual within the boundaries of his own domain is nobody else's business. If the dangerous effects of the contamination spread beyond those boundaries or if there is a reasonable probability of such spreading, it is practically certain that the courts will hold that the public health and welfare are involved and that the situation is amenable to the police power of the state.

Substantiating Evidence

All that has been said points to the fact that the investigators and technicians in this field have a prodigious job of education. They must collect and spread information about the facts of the situation in order to arouse the public and the legislators to the need for action, providing the basis for laws and regulations. They will have the never-ending task of securing, preserving, and presenting evidence for enforcement of laws and regulations. They must be prepared to support their reports with factual evidence that will stand up under attack. They must establish sound standards based on reliable factors, not on speculation or guesswork. They must be ready to explain technical terms, such as pH and BOD, and interpret their findings in language that legislators, judges, jurors, and laymen generally can understand.

All this emphasizes the need for training of personnel for these purposes and for great expansion of the present inadequate staffs and means for research, investigation, and inspection in the field of ground water contamination.

LEVEL OF CONTROL

Federal Control

Although, as will be further discussed, the states are primarily responsible for direct action for control of ground water contamination, as with surface water pollution, the federal government also has a large stake in the program. It is not likely that there will be much need for the direct exercise of federal authority in ground water contamination cases, as there may be in pollution of interstate surface waters. The effects of a given source of ground water contamination do not usually spread as far or as fast as surface water pollution, the few cases of ground water contamination that extend across state lines can probably be handled by joint action of the state or local authorities, or perhaps under an interstate compact, without federal intervention.

The federal government has a clear call to promote a general ground water contamination control program because of the national interest in protection and conservation of water resources, which are essential to the health, strength, prosperity, and survival of the entire country.

On the whole, the role of the federal government in the field of ground water contamination will involve the same objectives as with surface water pollution, with less emphasis on direct action and greater emphasis on promotional activities such as:

1. Alerting state and local agencies and others concerned to the problems involved.

2. Assisting state and local agencies in development of adequate laws and regulations.

3. Conducting research and field investigations of national interest, and assisting states with their research and investigation programs.

4. Providing technical assistance to the states, when desired, on special problems that they are not equipped to handle.

State Control

The primary responsibility for enacting and enforcing laws concerning ground water contamination rests upon the states, the same as in other fields requiring the exercise of the police power to control the conduct of individuals or public or private corporations in local matters. Hence, so far as direct action in prevention, abatement, or control of ground water contamination is concerned, the laboring oar must be pulled by the states and their subordinate agencies – counties, cities, villages, rural towns, sanitary districts, or other governmental units.

It must be remembered that in operations of this kind a city, county, or other local governmental unit, although it has considerable freedom of action, is serving as an arm of the state government, subject to state law, and exercising the power of the state by virtue of authority delegated.

The ground water contamination situation obviously presents organizational and administrative problems and related legal problems, of great complexity and difficulty, that each state will have to solve for itself. All we can do here is point out some of the requirements that must be met and indicate possible solutions.

The first question confronting state authorities in planning the development of effective programs for control of ground water contamination and the enactment of necessary related legislation is whether the program should be headed up by the State Board or Department of Health or the State Water Pollution Control Agency or some other state agency. This is a matter of policy that must be determined by the legislature in relation to the existing structure of the particular state government. For further observations on that phase of the problem, reference may be made to the discussion on Legal Aspects of Water Pollution Control at the National Conference on Water Pollution(1).

It should be noted that public health factors are much more important, relatively, in ground water contamination than in surface water contamination, because of the widespread use of ground water for domestic purposes as well as for municipal water supplies and because of the equally widespread use of septic tanks and cesspools in unsewered areas. In the past those facilities usually have been the concern of state health authorities, so far as the state has paid any attention to them.

Ground water also is used extensively for industrial processes, air cooling of buildings, irrigation, and other purposes not connected with public health, and many municipalities and industries dispose of sewage and waste underground. State supervision or control over such matters has usually been exercised by state water conservation or water pollution control agencies wherever such agencies have been created.

Without attempting here to go any further into the details of the problem, which will be discussed by others on this program, we may say that it is important to work out an effective arrangement for division of labor and coordination of functions in the ground water contamination control program among the different agencies concerned in each state, as has already been done in a number of states in general water pollution control programs. This is a problem to which the state legislatures, with the advice of administrative experts and legal counsel, should address themselves without delay if they are interested in promoting effective control of ground water contamination.

Incidentally, a recent check of state statutes by the staff of the Public Health Service at Washington showed that in about half the states the water pollution control agencies have jurisdiction over both surface water and ground water, whereas in the remainder such jurisdiction extends only to surface water. There is no sound reason for such a limitation. Because of the inseparable interrelationship between surface water and ground water in many situations involving pollution, the water pollution control agency should have jurisdiction over both. The same is true of the state health agencies. Any division of responsibility between the two types of agencies or any limitation on the authority of either should be based on functional considerations, not on the variable line between surface water and ground water.

Local Agency Operations

The most staggering aspect of the situation is the vast number of scattered installations (septic tanks, wells, etc.) that will have to be brought under supervision and control. To that end the manpower and means for the job will have to be multiplied far beyond the present forces of the state and local agencies concerned.

Conceivably the forces of the state agencies (State Board of Health, State Water Pollution Control Board, etc.) could be extended to handle the task. State-wide systems for inspection of local establishments, such as hotels and restaurants, are already in operation in many states.

It is obvious that a state-wide system for control of ground water contamination would require a much larger force of personnel and would involve the handling by state authorities of a much larger volume of local cases than any other operation yet undertaken directly by state administrations. The probability is that as a matter of practical expediency a combination system will have to be developed under which state agencies will exercise general supervision, whereas the bulk of the work of making investigations, issuing permits or licenses, and enforcing regulations will be done by local agencies under the general direction of state authorities.

In addition to general supervision and control, it would no doubt be desirable if not necessary for the state also to provide financial aid to local agencies to assure the effective operation of such a system. Under a system of that kind the forces of local agencies already engaged in similar operations would have to be expanded and strengthened. Furthermore, new local agencies, such as sanitary districts, with adequate authority would have to be created for areas not within the jurisdiction of existing local agencies.

State legal authority and machinery would have to be extended and strengthened in order to secure uniformity in regulations (with due allowance for differences in conditions) as well as in administration and enforcement. In so far as local governmental units may be authorized to adopt regulations, they should be required to meet certain minimum standards set by state law. Appropriate state laws and regulations should be made applicable to all areas outside the jurisdiction of local governmental units.

PROGRAM FUNDING

Obviously important to a successful program is the provision of sufficient funds to support effective research, investigation, administration, and enforcement operations all along the line. Without such implementation the most comprehensive laws are nothing but a set of empty gestures. This is another task to which the administrative and legal experts had better address themselves at once if they expect to get going with any kind of a successful ground water contamination control program.

The general water pollution control program has already imposed heavy financial burdens, with more to come, on the federal, state, and local governments throughout the country. The prospect of shouldering a larger load to cope with ground water contamination will not be greeted with enthusiasm by the taxpayers. Neither will the supporters of the general water pollution control program look with favor on diverting any revenue now earmarked for other uses to the ground water program except so far as the interests affected by the general program may benefit.

Within the time allotted here we cannot go into finances in detail. We may suggest however that in all fairness the major part of the financial load entailed by control of ground water contamination should be carried by those who are responsible for the problem, i. e., the great host of users of septic tanks, wells, and all other facilities for underground disposal of sewage or wastes from which ground water must be protected.

The value of their property is greatly enhanced by such facilities, and they can well afford to pay for whatever public service may be required to safeguard the public health and welfare.

Provision for raising funds from those responsible for the problem can be made through fees charged for permits for installation of facilities, with annual fees for continued maintenance, and also fees for the licensing of persons engaged in installation or servicing of facilities. The charging of fees for such purposes is common in other lines and certainly would be justified in principle in the field of ground water contamination control. It might not be possible to meet the entire cost in this way, but it would certainly go far to reduce the draft on general tax revenue.

LEGISLATION

Federal Water Pollution Control Act

The present Federal Water Pollution Control Act as amended, public law 660, 84th Congress, is broad enough to cover most if not all of the operations that the federal government would need to undertake in furtherance of an effective nationwide ground water contamination control program. Under the provisions of Section 2 and others, underground waters are already included in the purview of the Act for the purposes of all the general promotional functions for which federal action is authorized.

It is true that under Section 8 of the Act the exercise of federal enforcement authority is limited to interstate waters, which are defined in Section 11 (e) as "All rivers, lakes, and other waters that flow across, or form a part of, boundaries between two or more states." Conceivably this definition might include underground streams or bodies of water intersected by state boundary lines. Obviously it would not include percolating ground water in the interstices of the soil; however, as pointed out before, it is not likely that there will be much if any need for the exercise of federal authority in cases involving that type of ground water, even where the effects extend across state lines.

Extension of the federal Act to cover such cases might involve some constitutional questions, but we need not bother to consider them here in the absence of any pressing need for action in this connection.

State Legislation

It is clear from the foregoing observations that much new state legislation will be needed to meet the challenge of ground water contamination. Strangely enough, the replies to the American Water Works Association Task Force Questionnaire indicated that a large majority of the state agencies believed that their present laws were adequate. No doubt this resulted from the fact that the statements were made chiefly by state health agencies concerned with the safety of water supplies. Most if not all of those agencies probably do have authority to take some kind of action to prevent the spread of disease from contaminated ground water.

Whether that authority is adequate or not in itself, it is certain that the laws in most states are inadequate to provide for all the regulatory and constructive measures that will be required for a fully effective program for control of ground water contamination. If the authorities of any state, after reviewing the essentials for such a program, still think that their laws are adequate, they are indeed in a fortunate situation. We have an idea that most state agencies will concede that much remains to be done to bring their laws on the subject to the point of adequacy.

It is true that a number of states already have laws dealing with various particular ground water contamination problems, i.e., permits for drilling wells, licensing of well drillers and scavengers, etc., are required. State and local regulations relating to wells, septic tanks, and other facilities affecting ground water are in force in many places. New measures in this field are under consideration in several state legislatures, as indicated by the Public Health Service Bulletins. Such measures will be fully reviewed and digested for future use. At any rate, it is safe to say that no state has all the laws it needs for a thorough job of controlling ground water contamination.

Suggested State Water Pollution Control Act

As announced at the Washington conference, the Public Health Service staff are engaged in revising the original Suggested State Water Pollution Control Act of 1950; a new edition is to be issued sometime this year. We welcome the cooperation in that effort of all concerned throughout the country, including those present at this Symposium.

The original suggested act of 1950 included both ground water and surface water within the scope of its provisions; however, it did not deal directly with special problems of ground water contamination. The extent of the need for action on those problems was not apprehended at that time. It is certainly recognized now. In the forthcoming revision, ground water problems will get a full share of attention, along with surface water problems.

To that end all state health agencies, water pollution control agencies, and others concerned are invited to submit suggestions for desirable provisions for the purposes of ground water contamination control. Such suggestions, together with the information and ideas presented at this Symposium and other available material, will be fully considered in connection with the preparation of a preliminary draft for the revised suggested act. That draft will then be circulated among all agencies concerned for further comments, criticisms, and suggestions. With these benefits the final text of the revised act will be written and published. This may be accompanied or followed by supplementary bulletins on special legal problems of ground water contamination, if that appears desirable.

CONCLUSION

Although this discussion was supposed to deal with legal problems, it has branched out at some points into other fields, and one more digression may be permitted at the windup. It is important from any standpoint to remember that this is a free country in which all legislation, all provision of public funds, and all progress in public affairs depends on public support. All who are concerned with promoting an effective program for control of ground water contamination therefore should move with all possible speed and with every means available to inform the public about the facts of the situation and arouse them to the need for action.

To that end it will be necessary to enlist the cooperation of all the great conservation and public welfare organizations (including both men and women) whose aggressive action has been largely responsible for the advancement of the general water pollution control program. They will have to marshal their forces all the way from Washington to every state capital and down to the cities, villages, and rural towns throughout the country to get public backing to meet the needs of this problem. They will have to carry on the fight against ground water contamination with the same zeal that they have exhibited in combating water pollution in general.

Some of them may ask why they should get steamed up about underground contamination. Aside from the general interest in public health, the main impetus for the nationwide drive against water pollution has been the demand for cleaning up lakes and streams for recreational use -- boating, swimming, fishing, hunting, and all the other aquatic pursuits to which people are flocking in ever-increasing numbers throughout the country. Admittedly, outdoor recreation is essential to the future vitality of the nation, and water sports are a major factor in that field.

Those who have their minds on surface water for recreation or any other use must remember that surface water and ground water are inseparably interrelated in the natural order of things. They represent different stages in the same hydrologic cycle. What is surface water today may be ground water tomorrow and vice versa. Both types are part of the same total world supply of H_2O.

Furthermore, the ground is nature's reservoir for storing water with minimum loss from evaporation. When surface water is abundant, the surplus can be stored underground to be drawn upon when the supply of surface water is short. Ground water is used not only for domestic, industrial, and agricultural purposes but is pumped out in large quantities to maintain lake and stream levels for public recreational use and for maintenance of shore line property values in many places. Contaminated ground water cannot be used for that purpose. Moreover, if the supply of ground water available for any use is curtailed by contamination, it will mean heavier drafts on lakes and streams and perhaps exclusion of the public, thereby reducing their value for recreation and other nonconsumptive uses. In short, reduction of total available ground water ultimately means a corresponding reduction in total available surface water.

All in all, the conservationists, recreationists, and all others concerned with maintaining lakes and streams have as big a stake in combating ground water contamination as they have in fighting surface water pollution. Besides that, everyone is vitally concerned with protecting the public health. On all counts, there is no cause that deserves or demands more widespread public support than the program for control of ground water contamination.

REFERENCE

1. Wilson, Chester S. Legal Aspects of Water Pollution Control, Proceedings, The National Conference on Water Pollution, pp. 354-384, Supt. of Documents, U. S. Gov. Printing Office (1961).

REGULATIONS FOR PROTECTION OF GROUND WATER QUALITY IN MINNESOTA

L. Woodward, Minnesota Department of Health

Considering the recent occurrence of widespread ground water contamination in the Twin City suburbs, one might assume that the text of this paper could be much shorter than the title. It is true that little has been done toward prevention of the use of on-site sewage disposal systems for individual homes in the area and that in many instances soil absorption has been used as the means of final disposal for larger installations such as schools, apartments, and commercial establishments. In the latter installations, however, the need for large volumes of water has necessitated development of wells in the deeper, more productive formations. These formations have not shown the effects of sewage discharged near the surface, although some of the older wells that terminate in the deeper formations and do not have protective construction through the contaminated strata have shown evidence of increasing concentrations of chemicals attributed to sewage.

Prevention of the contamination of the shallow ground water in such an area requires more than the prohibition of the use of soil absorption as a means of sewage disposal. The only other means available at points beyond the reach of established sewerage systems would have been discharge of effluent into the small lakes or streams, some times dry, or the use of ponds or lagoons. The former could not be permitted, and the latter would probably feed the ground water in much the same manner as the tile fields or overflow into the same lakes and streams. The only feasible prevention would be rigid control of subdivision development to permit building only in areas where suitable sewage outlets could be made available. There is no State law to provide this control, but local governments are in no position to apply such a law until their over-all sewage disposal problem can be solved. It is likely that, if ground water were not so easily obtained on an individual basis, the pattern of suburban development would have been quite different, with orderly growth outward from the existing facilities instead of by the leapfrog system common in the area.

Local Control

Several villages have attempted to avoid becoming involved in municipal water and sewer systems by providing adequate separation between on-site wells and sewage disposal systems through requirement of larger and larger lots. In several villages nothing less than 2 acres is accepted, and at least one village has placed the requirement at 10 acres. This would appear to be a short-sighted principle, since the cost of supplying community services, when they do become necessary, will be prohibitively high.

State Water Supply Standards

Adherence to the standards of the State Board of Health is not mandatory except where made so by official action. Some communities have adopted the standards by ordinance, and the Commissioner of Agriculture has adopted them for pasteurization plants, cheese plants, creameries, and other food processing plants. They are applied by the State Board of Health in examination of plans for water supplies that will serve the public or any considerable number of persons. The submission of such plans is required by a regulation adopted in 1917. As applied to small individual wells, the standards do not make provision for wholesale use of individual systems of water supply and sewage disposal in builtup areas. In other words, such systems can be expected to operate satisfactorily in isolated situations but cannot be considered suitable as a substitute for properly designed community systems in areas of high population density.

The standards as applied to public installations are amended from time to time as new knowledge becomes available, and they are modified as necessary to meet the requirements of specific localities. The Minnesota Department of Health did not have experience with the hazards of limestone until long after some other states had become well acquainted with this problem. Only a relatively small part of the State has this problem, but that area contains about half of the State population. Following an incident in 1956 the standards were revised to require new wells to be cased with cement grout through unsafe rock formation. Figure 1 shows the manner in which this construction provides increased safety in conditions typical of the geology of the Twin City area.

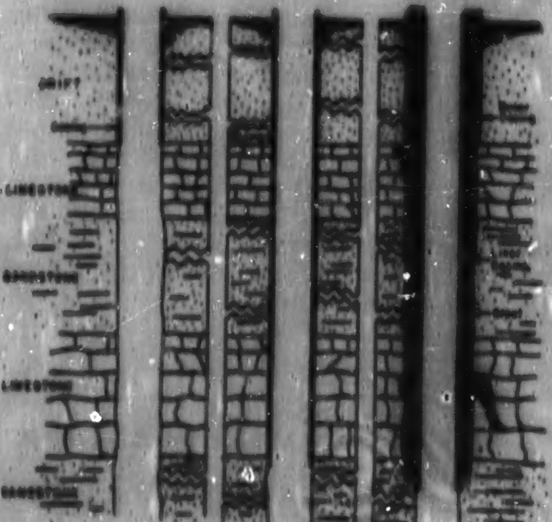

FIGURE 1. WELL CONSTRUCTIONS IN ROCK FORMATIONS

Department of Conservation

State law gives the Commissioner of Conservation considerable statutory authority over ground water. One section of the law requires that permits be obtained for appropriation of either surface or ground water. This section does not apply to domestic wells serving fewer than 25 persons. There are also limitations on application outside of certain muncipalities. The Commissioner may require the owners of artesian wells to control them to prevent waste.

Well drillers are required by law to furnish to the Department of Conservation a statement containing the log of material and water encountered in drilling a well and the results of all water pumping tests. This provides valuable information for various kinds of studies of water geology, including determination of the ultimate capacity of the aquifers, rates and direction of water movement, the effects of multiple pumping, and the possibility and feasibility of artificial recharge.

Water Pollution Control Agency

The State Water Pollution Control Commission has authority to control pollution of the waters of the State. Although some persons question the inclusion of ground water in the definition of "waters of the State" and an amendment to the Water Pollution Control Act to clarify this matter is being considered, the Commission has been effective in preventing the discharge of industrial wastes into the ground in many situations. This control is exercised through refusal to grant a permit for such disposal. Some proposals to establish industrial plants have been abandoned, or a proposed plant has been relocated at a point where surface disposal could be safely carried out. Among the wastes for which a permit for underground disposal has been denied or the method of disposal changed are: ammonia products wastes, sulfite liquor, vegetable canning wastes, wastes from corn silage stacks, wastes from pilot studies of detergents and other cleaning compounds, laundry wastes, creamery wastes, and plating wastes.

Regulation Through Control of Well Drilling

For a number of years the State Board of Health had a regulation that prohibited the use of a deep well or an abandoned well as a receptacle for sewage or household waste. In a recodification, this regulation was found to be inadequate for the intended purpose and it was rescinded. Nevertheless, the Board has been successful in accomplishing satisfactory closure of many abandoned wells where a public water supply has been involved. Such closure consists of filling the well with concrete through the rock formations to prevent the travel of water directly from an unsafe formation to the one used as the source of a neighboring well. One problem with this procedure, however, is that the municipality sometimes prefers to maintain the old well for emergency standby service.

For the past several legislative sessions the local and state associations of well drillers have endeavored to secure the enactment of a State licensing law for well drillers. Such a law would give the State Board of Health more definite authority to regulate drilling. These efforts have been unsuccessful largely because the industry was not fully organized in support of the measure. Such support has apparently been achieved for a bill under consideration at the present legislative session. This bill was prepared as a joint enterprise of the drillers, equipment companies, State Department of Conservation, State Board of Health, and the legislative interim commission on municipal laws. In addition to licensing of well drillers and pump installers, the bill authorizes the Board to develop a State well code in the form of regulations. Such regulations would contain provisions for proper control of abandoned wells and also of drainage wells constructed for the purpose of removing surface water. If this legislation is not enacted, the State Board of Health probably will enact regulations on this subject under existing authority.

FLORIDA REGULATIONS PERTAINING TO GROUND WATER CONTAMINATION

H. Baker, Jr., Florida State Board of Health

Nearly the entire State of Florida is underlain by porous and permeable limestone, which provides large supplies of ground water.

At present, approximately 90 per cent of the state's population depends on ground water for domestic use. In addition, large amounts are used for industry and for irrigation of vegetables and fruit crops.

We have had a review of types of contamination, with reports on specific incidents, so I would like to call to your attention one such case in Florida. The following letter is self-explanatory. (Remember this was 56 years ago.)

"Key West, Fla., May 13, 1904

"To His Excellency, W.S. Jennings,
Governor of Florida,
Tallahassee, Florida,

(Through Hon. E.M. Hendry, president State Board of Health).

"Dear Sir:

"I beg respectfully to invite your attention to the great apparent necessity for soliciting the cooperation of the United States Geological Bureau in determining the course of the underground water streams of the state. The State Board of Health is confronted with a most serious problem in connection with the potable water supply of many towns, associated as it is with the disposal of domestic waste. Where towns are located on river banks, sounds, or on the ocean, the disposal of sewage is not a difficult question to adjust, but many of the inland towns whose population has grown quite rapidly during the past ten years, seek how to adopt a more convenient and satisfactory method of disposing of sewage and have placed in operation a sewer system at the same time that a water works plant was established.

"In not a very few of these inland towns the sewage is run into a 'sink hole', of which there are a number in the central and western part of the state, and the sewage passes to where no one knows.

"In one instance, at Live Oak, there is this disposal of sewage, and I have lately caused the public water supply of that place to be examined bacteriologically, and the Bacteriologist of the Board reports that he found the sample of water sent him to be contaminated with the colon bacillus, the bacillus which infects the intestinal tract of the human.

"It is therefore conclusive evidence to my mind that there is some connection between the stream of water at the bottom of the 'sink hole' at Live Oak and the well of the water plant at that place. This present contamination produces intestinal disorders, and many of the physicians lately in attendance on the State Medical Association at Live Oak were affected by diarrhea and other intestinal discomforts."

Over the years, ground water contamination has been identified in the following cities and counties in Florida:

Live Oak - Suwannee
Gainesville - Alachua
High Springs - Alachua
Orlando - Orange
Lake City - Columbia
Sanford - Seminole
Ft. Myers - Lee
Ocala - Marion

A survey made in 1948, entitled "The Pollution of Artificial Ground Waters in Suwannee and Orange Counties, Florida by Artificial Recharge Through Drainage Well" covers two of the incidents (see annex).

Florida is not without its problems pertaining to ground water contamination. Waters of varying degrees of pollution have been discharged into underground waters for many years. Even today considerable quantities of treated municipal sewage, as well as highly organic industrial wastes, are being disposed of in this manner.

The State Board of Health issues permits for drainage wells (Chapter XXI Florida State Sanitary Code - see annex), and it has been the policy to prevent any increase in the amount of highly polluted waste being discharged into the ground. Heat, however, has not been considered a pollutant, and the use of drainage wells that terminate in fresh water strata is permitted for disposal of heated water if it is passed through closed cooling systems without contact with the atmosphere.

Enforcement of pollution control legislation in Florida has been vested largely in the State Board of Health. Its most important weapon is the Pollution of Waters Act of 1913. This act forbids any deposit of deleterious substances in the state, if such substances are "liable to affect the health of persons, fish or livestock." The statute covers pollution of lakes and ground waters as well as streams. Enforcement of this law is placed under the supervision of the State Board of Health. On its face the statute seems broad enough to prevent all undesirable pollution of Florida's streams, but the act had no provisions for injunctive enforcement - criminal penalties were provided only for its violation. The number of complaints concerning industrial pollution in the early Fifties indicated that this law, as it existed, was largely ineffective. Effort by the State Board of Health resulted in amendment in 1955 of the chapter enumerating the general powers of the board. This amendment gives the board the power "to enjoin and abate nuisances dangerous to the health of persons, fish and livestock." This amendment has proved helpful to the board in its pollution control work.

Two other general laws, an act dealing with waste from mines and the [illegible] County Water System and Sanitary Financing Act, authorize boards of county commissioners to seek injunctions against certain types of pollution.

Related to pollution control by state authorities are two Florida special acts that should be discussed. These acts declare Nassau and Taylor counties to be industrial counties; the acts further state that it is in the interest of the public that industry be empowered to discharge sewage and industrial and chemical wastes into the tidal waters of Nassau County and into the Fenholloway River and the waters of the Gulf of Mexico, into which the Fenholloway River flows. Some authorities believe that this legislation, if attacked, might well be held unconstitutional on the ground that it deprives the riparian owners on these waters of property rights, without compensation, in violation of the state and federal constitutions. If the industry owns the land on both sides of the river, the point in question is debatable. The Florida Statutes, as written appear in the annex (Statutes 387 and 381).

With reference to the administration of these Statutes, it is necessary that I refer you also to Chapter XXXV of the Florida State Sanitary Code, entitled "Administrative Regulations and Enforcement of Code" (see annex). In this Chapter the local health officers are deputized by the State Health Officer for the purpose of carrying out the provisions of the Sanitary Code of the State of Florida and are designated as agents of the State Board of Health and deputies to the State Health Officer, within the geographical jurisdiction of their organization.

At the present time, the State Board of Health has one general counsel and one full-time counsel who is available for work both in county health departments and within the State Board of Health. The over-all policy of the State Board of Health has been and is one of persuasion, conciliation, and "be a good neighbor," with attempts to educate and work with the various offenders, rather than pursue the legal phase. A large portion of the work is accomplished through good professional relationships.

Much progress has been made within the State of Florida, and although the population has doubled approximately every decade, we hope that additional progress can be made without too much use of so-called "police" powers.

REFERENCES

1. Florida Statutes
2. Florida Sanitary Code
3. Florida Water Resources
   Report, 1957
4. John S. Telfair, Jr.,
   Report, 1948
5. Florida State Board of Health
   Annual Report, 1904

FLORIDA STATE SANITARY CODE

CHAPTER XXI

Drainage Wells

(Reference is made to Chapter 381 and Chapter 387 of the Florida Statutes.)

These statutes place the sanitary control of all waters of the State of Florida under the jurisdiction of the State Board of Health.

Section (1) Drainage well defined. A drainage well referred to in these regulations is any cavity drilled or natural which taps the underground water and into which surface waters, waste waters, industrial wastes, or sewage is placed.

Section (2) Application for approval. Before entering into a contract for the [illegible] of a drainage well it shall be the responsibility of the well drilling contractor to make application to the State Board of Health. Drilling shall not be begun until the proposed construction is approved by written permit signed by the Director of the Bureau of Sanitary Engineering of the State Board of Health.

Section (3) Data to be submitted with application. The application shall be accompanied by the following data:

(a) Location, depth, depth of casing of all wells used for water supply within a one mile radius of the proposed well.

(b) Nature of wastes to be placed in the proposed well with analysis if deemed necessary.

(c) Additional data as may be required by the State Board of Health.

Applications shall be signed by:

(1) The well drilling contractor, and
(2) The owner or the duly authorized representative of the owner.

Section (4) Submission of logs. A log showing the various strata pierced by the well shall be forwarded to the State Board of Health within 2 days after completion of the drilling operation. Samples of the various formations pierced in the drilling operation shall be forwarded to the State Geologist when the drilling operation has been completed.

Section (5) Wastes prohibited from disposal to drainage wells. Drainage wells shall not be used for the disposal of human wastes, or any waste deemed by the State Board of Health to be injurious to the public health.

Section (6) Casing. First quality lap-welded pipe only shall be used as a casing material. The use of butt welded pipe is prohibited.

The practice of dynamiting wells which have become clogged shall not be resorted to except with permission of the State Board of Health.

Section (7) Rights of Municipality. No government agency, municipality, county, or organization shall have the right to require the placing of any wastes in a drainage well. This is the function of the State Board of Health only.

The sections of this Chapter were adopted by the State Board of Health in executive session on February 16, 1946, to be effective from that date.

POLLUTION OF WATERS

Chapter 387, Florida Statutes

387.01 "Underground Waters of the State" Defined. The term "underground waters of the state", when used in this chapter, shall include all underground streams and springs and underground waters within the borders of the state, whether flowing in underground channels or passing through the pores of the rocks.

387.02 Permit Required for Draining Surface Water or Sewage into Underground Waters of State. No municipal corporation, private corporation, person or persons within the state shall use any cavity, sink, driven or drilled well now in existence, or sink any new well within the corporate limits, or within five miles of the corporate limits, of any incorporated city or town, or within any unincorporated city, town or village, or within five miles thereof, for the purpose of draining any surface water or discharging any sewage into the underground waters of the state, without first obtaining a written permit from the state board of health.

387.03 Permits Revocable and Subject to Change; Notice by Publication; Filed with Clerk. Every permit for the discharge of sewage of surface water, shall be revocable or subject to modification or change by the state board of health, on due notice, after an investigation and hearing, and an opportunity for all interests and persons interested therein to be heard thereon; said notice or notices being served on the person or persons owning, maintaining or using the well, cavity or sink, and by publication for two weeks in a newspaper published in the county in which said well, cavity or sink is located. The length of time after the receipt of the notice within which it shall be discontinued may be stated in the permit. All such permits, before becoming operative, shall be filed in the office of the clerk of the circuit court of the county in which such permit has been granted.

387.04 Sewage Defined. For the purpose of this chapter, sewage shall be defined as any substance that contains any of the waste products, excrement or other discharge from the bodies of human beings or animals.

387.05 Sewage or Surface Drainage into Underground Waters of State to be Discontinued within Ten Days after Order by State Board of Health. Every individual, municipal corporation, private corporation or company shall discontinue the discharge within the corporate limits or within five miles of the corporate limits of any incorporated city or town, or within any unincorporated city, town or village or within five miles thereof, of sewage or surface drainage into any of the underground waters of the state within ten days after having been so ordered by the state board of health.

387.06 Penalty for Violation of Provisions of this Chapter. Any municipal corporation, private corporation, person or persons that shall discharge sewage or surface drainage, or permit the same to flow into the underground waters of the state, contrary to the provisions of this chapter, shall be deemed guilty of a misdemeanor and shall, upon conviction, be punished by a fine of twenty-five dollars for each offense or by imprisonment not exceeding one month. The doing of the prohibited act for each day shall constitute a separate offense.

387.07 Penalty for Interference with Water Supply. Whoever willfully or maliciously defiles, corrupts or makes impure any spring or other source of water reservoir, or destroys or injures any pipe, conductor of water or other property pertaining to an aqueduct, or aids or abets in any such trespass, shall be punished by imprisonment not exceeding one year, or by fine not exceeding one thousand dollars.

387.08 Penalty for Deposit of Deleterious Substance in Lakes, Rivers, Streams, Ditches, etc. Any person, firm, company, corporation, or association in this state, or the managing agent of any person, firm, company corporation or association in this state, or any duly elected, appointed or lawfully created state officer of this state, or any duly elected appointed or lawfully created officer of any county, city, town, municipality, or municipal government in this state, who shall deposit or who shall permit or allow any person or persons in their employ or under their control, management or direction to deposit in any of the waters of the lakes, rivers, streams, and ditches in this state, any rubbish, filth or poisonous or deleterious substance, or substances, liable to affect the health of persons, fish, or livestock, or place or deposit any such deleterious substance or substances in any place where the same may be washed or infiltrated into any of the waters herein named, shall be deemed guilty of a misdemeanor, and, upon conviction thereof in any court of competent jurisdiction, shall be fined in a sum not more than five hundred dollars; provided, further, that the carrying into effect of the provisions of this section shall be under the supervision of the state board of health.

387.10 Proceedings for injunction.

(1) In addition to the remedies provided in this chapter and notwithstanding the existence of any adequate remedy at law, the state health officer or other appropriate officer of the state board of health is authorized to make application for injunction to a circuit judge, and such circuit judge shall have jurisdiction upon a hearing and for cause shown to grant a temporary or permanent injunction or both restraining any person from violating or continuing to violate any of the provisions of this chapter or from failing or refusing to comply with the requirements of this chapter, such injunction to be issued without bond provided, however, no temporary injunction without bond shall be issued except after a hearing of which the respondent or respondents has or have been given not less than seven days prior notice, and no temporary injunction without bond, which shall limit or prevent operations of an industrial, manufacturing or processing plant shall be issued, unless at the hearing it shall be made to appear by clear, certain and convincing evidence that irreparable injury will result to the public from the failure to issue the same.

(2) In event of the issue of a temporary injunction or restraining order hereunder without bond, then the state, in event said injunction or restraining order was improperly, erroneously or improvidently granted, shall be liable in damages and to the same extent as if said injunction or restraining order had been issued upon application of a private litigant instead of a public litigant, and the state hereby waives its sovereign immunity and consents to be sued in any such case.

LAWS PERTAINING TO THE SANITARY CODE

Excerpts of Chapter 381, Florida Statutes

381.031 Duties and Powers of the Board. It shall be the duty of the board to **adopt, promulgate, repeal and amend rules and regulations consistent with law regulating*** prevention and control of public health nuisances; sanitary practices relating to drinking water made accessible to the public; watersheds used for public water supplies; disposal of excreta, sewage or other wastes; the disposal of garbage and refuse; plumbing; rodent control; pollution of lakes, streams and other waters; drainage and filling in connection with the control of arthropods of public health importance; production, handling processing and sale of food products and drinks including milk, dairies and milk plants; canning plants, shellfish dealing and handling establishments, restaurants and all other places serving food and drink to the public; toilets and washrooms in all public places and places of employment; factories, trailer, tourist, recreation and other camps offering accommodations to the public; swimming pools and bathing places; state, county, municipal and private institutions serving the public; jointly with the state board of education, public and privately owned schools; vehicles offering transportation to the public; all places used for the incarceration of prisoners and inmates of state institutions for the mentally ill; and any other condition, place or establishment necessary for the control of communicable diseases or the protection and safety (light and ventilation) of the public health; control of arthropods of public health importance; prescribe qualifications of operators of milk plants, water purification plants, sewage treatment plants and swimming pools; *the pollution of the air where created on private property, in public places, by industrial waste disposal or sewage disposal or in any place or manner whatsoever; ***and bedding inspection.

The board may commence and maintain all proper and necessary actions and proceedings for any or all of the following purposes: (a) To enforce its rules and regulations; (b) to enjoin and abate nuisances dangerous to the health of persons, fish and livestock; (c) to compel the performance of any act specifically required of any person, officer or board by any law of this state relating to public health; (d) to protect and preserve the public health; and (e) it may defend all actions and proceedings involving its powers and duties.

381.071 Regulations and Ordinances Superseded. The provisions of the rules and regulations adopted and promulgated by the board under the provisions of this chapter shall, as to matters of public health, supersede all regulations enacted by other state departments, boards or commissions, or ordinances and regulations enacted by municipalities; provided no provision of this chapter shall be construed as altering or superseding any of the provisions set forth in chapters 502 and 503, or any rule or regulation adopted under the authority of said chapters.

381.081 Presumptions. The authority, action and proceedings of the board and the state health officer and other agents of the board in enforcing the rules and regulations adopted by the board under the provisions of this chapter shall be regarded as judicial in nature and treated as prima facie just and legal.

381.091 Construction, Rules and Regulations: Nothing contained in the rules and regulations adopted by the board under the provisions of this chapter shall be construed as limiting any duty or power of the board provided by the statute laws of Florida.

381.101 Municipal Regulations and Ordinances: Any municipality may enact, in manner described by law, health regulations and ordinances not inconsistent with state public health laws and rules and regulations adopted by the board.

381.111 Power to Enforce: Any member of the board or any officer or agent of the board designated for the purpose may enforce any of the provisions of this chapter or any rule and regulations promulgated by the board under the provisions of this chapter. If necessary he may appear before any magistrate empowered to issue warrant in criminal cases and request the issuance of a warrant and said magistrate shall issue a warrant directed to any sheriff, deputy, constable or police officer to assist in any way to carry out the purpose and intent of this chapter.

381.121 Enforcement; City and County Officers to Assist: It shall be the duty of every state and county attorney, sheriff, constable, police officer and other appropriate city and county officials upon request to assist the state health officer or any other agent of the board in the enforcement of the state health laws and the rules and regulations promulgated by the board under the provisions of this chapter.

381.251 Pollution Control; Underground Water, Lakes, etc.: The board and its agents shall have general control and supervision over underground water, lakes, rivers, streams, canals, ditches and coastal waters under the jurisdiction of the state insofar as their pollution may affect the public health or impair the interest of the public or persons lawfully using them.

381.261 Supervision; Water Supply and Sewage Disposal: The board and its agent shall have general supervision and control over all systems of water supply sewerage refuse and sewage treatment in the state insofar as their adequacy, sanitary and physical conditions affect the public health.

381.271 Approval of Water: No county, municipality, person, persons, firm, corporation, company, public or private institution or community of more than twenty-five inhabitants shall install a system of water supply sewerage, refuse or sewage disposal, or materially alter or extend any existing system until complete plans and specifications for the installation, alterations, or extensions, together with such other information as the board may require have been submitted and approved by the board. The board may further make and enforce such specific rules and regulations regarding the submission of plans for approval and record as it deems reasonable and proper to carry out the provisions of this section.

381.281 Water Supply and Disposal System: Advisory Duty: The board shall consult with and advise any county or municipal authority or any other person as to the source of water supply, methods of water purification, and disposal of drainage, sewage or refuse. It shall also advise and consult with any manufacturer or other person conducting a business or intending to conduct a business whose sewage, waste or waste products may tend to pollute the waters of this state. The board may conduct experiments relating to purification of water and treatment of sewage, waste or refuse.

381.291 Corrective Orders; Water and Disposal Systems: When the board or its agents, through investigation, find that any system of water supply, sewerage, refuse or sewage disposal constitutes a nuisance or menace to the public health, it may issue an order requiring the owner to correct the improper condition.

381.311 Regulations for Municipal and County Sanitation: The board shall supervise and regulate municipal and county sanitation and shall exercise general supervision over the work of local health authorities. Local health officials and other appropriate local officials concurrently with the board shall enforce the provisions of the state sanitary code and other public health rules and regulations and of such local ordinances and sanitary regulations as may be consistent with it.

381.411 Penalties: Any person who violates any of the provisions of this chapter, any quarantine or any rule or regulation promulgated by the board under the provisions of this chapter is guilty of a misdemeanor and subject to be punished by imprisonment not exceeding six months or by fine not exceeding $1,000.00. Any person who interferes with, hinders or opposes any agent, officer, or member of the board in the discharge of his duties is guilty of a misdemeanor and subject to be punished by imprisonment not exceeding six months or by fine not exceeding $1,000.00.

FLORIDA STATE SANITARY CODE

CHAPTER XXXV

Administrative Regulations and Enforcement of Code

Section (1) State Health Officer Executive Officer of Board. The State Health Officer, as the executive officer of the State Board of Health, is designated to act for the Board in the enforcement of the State Sanitary Code and to carry out the administrative duties connected therewith.

Section (2) Staff of the State Health Officer. The staff of the State Health Officer, consisting of the directors of the Bureaus or other authorized divisions, are designated as agents of the Board, and, under supervision of the State Health Officer, will assume responsibility for carrying out the provisions of the Sanitary Code in their respective authority.

Section (3) Local Health Officers Deputized. Local Health Officers in health units organized under provisions of Chapter 154, Florida Statutes 1941, and such other local health officers as may be named and approved by the State Health Officer, are, for the purpose of carrying out the provisions of the Sanitary Code of the State of Florida, designated as agents of the State Board of Health, and deputies to the State Health Officer, within the geographical jurisdiction of their organization. Provided, however, that where approval of plans for sanitary work is required of the State Board of Health covering water works and sewerage and other sanitary structures, or where operating permits are required of the State Board of Health, their authority will be confined to recommendations to the State Health Officer or the central organization division concerned.

Section (4) Upon the discovery of a violation of any of the laws of the State of Florida under the general supervision of the

State Board of Health or of any rule or regulation made by the State Board of Health, where protection of the public health so requires or justifies, it shall be the duty of the State Health Officer or one of his deputies to post a notice of such violation on the premises where such violation exists and at or near the public entrance to such premises.

Section (5) Any person who shall violate, disobey, refuse, omit or neglect to comply with any of the rules and regulations of the Sanitary Code shall be guilty of a misdemeanor and upon conviction, shall be punished by imprisonment, not exceeding six months, or by fine not exceeding one thousand ($1,000) dollars.

Section (6) Any person who shall interfere with, or hinder, or oppose, any officer, agent or member of the State Board of Health in the performance of his duty as such, under the Sanitary Code, or shall violate a quarantine regulation, or shall tear down, mutilate, deface, or alter any placard, or notice, affixed to premises in the enforcement of the Sanitary Code, shall be guilty of a misdemeanor and punishable upon conviction, by imprisonment for not exceeding six months or by a fine not exceeding one thousand ($1,000) dollars.

The Sections of this Chapter were adopted by the State Board of Health in executive session on August 22, 1953, to be effective from that date.

THE GROUND WATER CONTROL PROGRAM OF WISCONSIN

O. J. Muegge, Wisconsin Board of Health

"Water, water, everywhere, but not a drop to drink." The condition cited in this widely known quotation could well become an actuality in some land areas if publicly supported, rigid controls are not maintained over our water resources. This could be as true in Wisconsin, a water-rich state lying in the Great Lakes and Mississippi River drainage basins, as in many other states not as well endowed with water resources.

In Wisconsin, the need for controls over water resources has long been recognized and acted upon. Thus, during the course of years, various state agencies have been vested with the responsibility of supervising specific phases of water resource management as the need arose. As part of such management, the State Board of Health is charged with the responsibility of protecting all waters "insofar as their sanitary and physical condition affects health or comfort." The Board also controls installation of high capacity wells, to prevent reduction in the availability of water to utilities distributing water to the public or other adverse effects.

WISCONSIN LAWS AFFECTING GROUND WATERS

The laws under which ground water quality, and to some extent quantity, has been controlled follow.

Early Laws

The early laws of Wisconsin that imposed some control over ground water sources were repealed upon enactment of more detailed acts. The early laws included one in 1876, which required that the Board advise local officials in regard to water supply systems serving public buildings and institutions, a second in 1879, which included plumbing regulations for municipalities with public water supply systems, and a third in 1905, which required municipalities to submit plans for public water works to the Board for approval.

Plumbing Law

The plumbing law enacted in 1913, which, although amended, is still in effect, provides for the licensing of plumbers working in communities that have water or sewerage systems and for the enactment of regulations, statewide in scope. This law initially gave control of private water systems to the Board (Chapter 145, Wisconsin Statutes).

Water, Ice, Sewage, and Refuse Law

The law pertaining to control over water, sewerage, and refuse disposal systems and over ice supplies was enacted in 1919. This act gave the Board general supervision over the waters of the state and required that any owner, upon request, submit plans and specifications of water works systems, new or modified, for approval. This law was amended in 1927 and again in 1949 to create and establish the responsibility of the Committee on Water Pollution for control of surface water pollution and treatment of industrial wastes. It was amended in 1945 also to require that owners obtain a permit from the Board for the construction or reconstruction of wells with a rated capacity of 100,000 gallons per day or more (Chapter 144, Wisconsin Statutes).

Pure Drinking Water Law

The pure drinking water law of 1935 provided for the registration of well drillers and the enactment of regulations covering well construction. This law was amended in 1953 to require registration of pump installers. The act does not provide for the registration of persons who install driven wells and is not applicable to wells not used as a potable water supply source; however, driven-point well construction must conform to regulations of the Board (Chapter 162, Wisconsin Statutes).

REGULATIONS

As far as is known, no regulations were enacted to govern water supply installations under the early laws. Later statutes did provide authority, however, for enforcement of regulations that had been adopted to control ground water quality.

Plumbing

The initial plumbing regulations were enacted in 1914. They have since been amended nine times and a tenth revision is under way. These regulations presently control the location of soil absorption sewage disposal systems and drainage piping with respect to wells and also the construction of sewers, septic tanks, and soil absorption systems. The minimum separation permitted between a private well and a soil absorption system is 50 feet, whereas the minimum permitted between a well and septic tank or sewer of other than cast iron pipe is 25 feet. Cast iron sewers with leaded joints may be installed to within 8 feet of a well. Soil absorption systems must be shallow tile fields or shallow leaching pits, and such pits may not extend into creviced rock. These minimum distances are tempered with practicality and, as will be indicated, are not the basic safety precaution against contamination.

Controls also are provided to prevent back-siphoning from fixtures and cross-connecting of dual sources of water supply. Until 1936 the plumbing regulations also included very general specifications for water supply sources and pumping equipment installations (Chapter H 62, Wisconsin Administrative Code).

Public and Institutional Water Supplies

Following enactment of Chapter 144, regulations were adopted that required submission of water works plan to insure certain standards of construction. These standards are minimal and are primarily applicable to water purification plants. These broad regulations generally assure, through plan approval of public water supply sources, well construction in accord with established policy based on commonly accepted practice. Regulations governing the location of public wells with respect to pollution sources are more restrictive than those applicable to private wells. The location may vary with type of well construction, geologic formations, and pollution source. Maximum separating distances, up to 200 feet, are required between sewers and shallow wells that obtain water from unconsolidated deposits. Minimum separation of 100 feet is required between ordinary sewers and wells in which the casings extend into sandstone. Lesser distances are permitted if the sewers are cast iron with leaded joints, and greater distances are required if soil absorption systems are used. Where feasible, wells are to be cased and grouted to a depth of at least 40 feet; however, casing depths to 500 feet are required in some wells. The termination of a casing in limestone, when such aquifer is used as the source of supply, is generally at a depth of 100 feet or more for public utility wells but may be at a depth as great as 300 feet. In areas where adequate casing depths cannot be attained, supplemental treatment or greater separation from pollution sources is required (Chapters H 51 and H 54, Wisconsin Administrative Code).

PRIVATE WATER SUPPLIES

Regulations applicable to well construction were authorized by pure drinking water legislation adopted in 1936. This legislation was amended five times; the regulations now in effect were adopted in 1951 and supplemented in 1953. These regulations set forth the requirements pertaining to private well location and construction and to pump installation. They also cover finishing, disinfection, and sampling of new or reconstructed wells, and the method of sealing abandoned wells. They provide less restrictive requirements for existing water supply systems; thereby, use of facilities installed in conformity with prior codes may be continued. Minor modifications of older facilities that will make these installations conform with provisions of former regulations are permitted.

The private well construction regulations, as well as those for public well construction, are designed with the intention of providing vertical protection of the wells rather than reliance upon distance of separation and the removal of contamination during horizontal travel of the ground water. The latter, however, is by no means overlooked, and the regulations specifically state that the well shall be located as far from sources of pollution as possible. Regulations with respect to minimum thickness of casing and the sealing of annular construction spaces with suitable material, and specifically with cement grout under certain conditions, contribute to initial vertical protection of the supply and to permanency of the well.

Since the casing or curbing of a well is the factor that provides vertical protection, its depth is most important. Requirements vary from a minimum depth of about 20 feet for drilled or driven wells located in unconsolidated deposits with high ground water pumping levels to depths of over 100 feet in consolidated creviced formations where such formations are initially encountered at relatively shallow depths. When creviced rock is encountered at depths of less than 40 feet, the casing must be grouted to at least 40 feet.

The 1951 regulations favored the discharge of water from the well at a point above the ground surface or at subsurface levels through pipes operating under pressure or enclosed in conduits. New well pits could be installed only with the approval of the Board. Reasons for this provision are well known to public health personnel.

Minimum distance requirements are the same as those specified in the plumbing code except that provision is made for greater separation between wells and sources of pollution where the vertical protection to be provided is not equal to the minimum required depth of casing. This variation from specified minimum depths is applied only in cases where the geologic formation makes water unattainable other than at shallow depths. This would be typical of some areas in northern Wisconsin where granite lies near the ground surface. In these areas, proper well location with respect to elevation and direction of pollution sources and greater separation requirements prevail. All wells deviating in the manner indicated or in other construction details from the regulations must be individually approved.

Action to locate and seal abandoned wells is essential if maximum protection for an aquifer is to be provided. The regulations therefore specify that wells temporarily removed from service be capped or filled with clay. Permanently inactivated wells are to be permanently sealed, filled with clay or concrete when in unconsolidated formations or plugged with concrete when the well penetrates one or more consolidated formations. The regulations further require that wells not be used to dispose of sewage or waste waters. Help in accomplishing the sealing of abandoned wells is provided by local officials, by well drillers, and by state agencies.

DISCUSSION OF REGULATIONS

The regulations for well construction in Wisconsin are based on the knowledge and theory that water penetrates vertically from the surface to the water table and then travels at or near the ground water table in the direction of underground flow, with maximum removal of contaminants during vertical rather than horizontal travel. This theory of horizontal travel of contamination would not hold with fluid material that has a specific gravity greater than that of water. In heavier materials the contaminant could be expected to penetrate to appreciably greater depths. This has been demonstrated in studies on soil disposal of sulfite liquor from paper mills. The theory of horizontal travel also will not hold if the aquifer does not have uniform porosity.

The more stringent requirements adopted in the later regulations for pump installations were enacted with the belief that designers or installers of pumping equipment would create acceptable sanitary devices for conveying water from wells to points of use. Since 1951 when the regulations favored elimination of well pits, considerable progress has been made in pump design and in adapter construction to provide for discharge of water under pressure from wells below the surface of the ground. When the regulations were enacted, only two devices for underground pressure discharge were available. Since that time, more than 20 additional devices have been developed for discharge of water under pressure without a pump enclosure at a subsurface or above-grade level. Use of pumphouses for protection of pumping equipment on private property generally has not proved too acceptable because of aesthetic reasons and the fear of freezing, should the power supply fail during cold weather. This objection to pumphouses has added initiative to the development of the improved well discharge equipment.

It should be noted that the regulations on well construction were developed to exclude bacterial contamination. Since enactment of the regulations, considerable information has been obtained on contamination of wells by detergents. To exclude detergents, greater attention probably needs to be given to increasing the depth of vertical protection and possibly also to increasing horizontal separation for greater dilution of the contaminant. The development of detergents that are subject to destruction or removal through natural purification processes seems however to offer a much better approach to this problem.

EDUCATION PROCEDURES VERSUS REGULATORY PROCEDURES

Much has been said about the need for educating the public on proper sanitary facilities of all kinds. Such educational approaches would necessarily cover the basic principles underlying good well construction and the consequence of contamination that might occur if a well installation is improperly made. If reliance is to be placed solely upon the educational approach, much time should be spent advising persons concerned of desirable well locations and types of construction, with the greatest emphasis placed on distribution of information to those that may be called upon for advice or those engaged in the construction of wells and installation of pumping equipment.

The adoption of regulations does not completely obviate the need for education but does tend to accentuate the interest of persons who may be involved in the design, construction, supervision, or ownership of wells and pumping devices. An educational approach in support of regulations has been utilized extensively in Wisconsin. Public hearings prior to enactment of regulations were supplemented with dissemination of information by way of manuals to persons engaged in construction. In addition, training on reasons for and objectives of specific requirements was given to persons with supervisory responsibilities, such as public health personnel, dairy plant fieldmen, and agricultural agents. Also, training programs were initiated for well constructors and pump installers on the interpretation of the regulations, preparation of construction reports, sampling methods, and other criteria. Distribution of leaflets calling attention to basic factors in good well construction through schools, 4-H clubs, and similar organizations also has helped bring about a receptive attitude on the part of all persons involved with well construction. Reliance is placed on other programs, such as the production of Grade A milk, hotel and restaurant sanitation, migrant labor camp certification, and high capacity well permits, to assist in bringing about satisfactory well construction.

ENFORCEMENT OF LAWS AND REGULATIONS

To provide through the law and regulations maximum benefits toward the procurement of ground water of high quality, it is necessary that laws and regulations be properly enforced. Enforcement consists of four procedures.

Investigation of Unregistered Persons

A constant watch is kept by Board personnel for the purpose of discovering unregistered persons who are performing well construction or pump installation work. Persons found through such surveillance initially are asked to become registered, if qualified. Should they fail to become registered, court action is initiated to collect penalties and also to require registration, if they prefer to continue in the business. Known wells constructed or pumping equipment installed by such persons are checked to determine compliance with the regulations. Improper installations are subject to correction by the installer or property owner.

Correction of Defective Work

When unsatisfactory well construction or pump installation is found to have been performed by a registered person, he receives notification in writing that correction is necessary to comply with the regulations or reasonably meet the purpose of the regulation. Such unsatisfactory work is uncovered through inspection and through review of well construction reports and water analyses that must be submitted by the well constructor following construction. Samples of water for analysis are also to be submitted to an accredited laboratory by the pump installers upon completion of their work. Enforcement by this method is facilitated by complaints from competitors, health officials, and fieldmen and through comparison of construction reports on adjacent wells. Considerable remedial work has been accomplished through this type of action.

Reporting of Work in Progress

Where the Board has reason to believe that wells are not being constructed in conformity with the regulations by a registered person, it may order the person to inform the Board of the location of wells under construction and the date of completion of such wells. Follow-up inspections are made on some but not all such wells. The fact that the Board has knowledge of the construction project tends to result in work that will meet construction requirements.

Registration Suspension or Revocation

Should it be found that a registered person failed to submit well construction reports or water samples or should it be discovered that such person is willfully violating the regulations, the Board may suspend his registration by filing a complaint and issuing a suspension order. This may be followed by revocation of the registration if the registrant fails to bring his records up to date or fails to correct improper installations. Registration can be suspended for a selected short period and can be revoked by order. Revocation of registration must be effective for at least 1 year.

Generally, suspension of the registration effectively brings about compliance with the regulations and submission of required reports and samples. This has been the most effective procedure for obtaining compliance with the regulations.

ACCOMPLISHMENTS

In general, when wells are constructed and pumps installed in accord with the regulations, a bacteriologically safe water is produced. In only a few cases has it been found that installations apparently made in accord with regulations have proved unsafe. In most good well constructions, problems associated with detergents have not occurred.

In conclusion, it might be said that laws providing for the registering or licensing of well constructors and pump installers, coupled with reasonable minimum regulations and with educational procedures, are effective in the procurement of uncontaminated drinking water supplies.

CONTROL OF GROUND WATER CONTAMINATION BY A COUNTY HEALTH DEPARTMENT

H. W. Davids, Suffolk County Department of Health

Suffolk County, with a population of over 700,000, comprises the eastern two-thirds of Long Island, New York, an area of approximately 920 square miles.

The county is blessed with an abundance of ground water, generally of excellent quality, derived entirely from rainfall. All water supply in Suffolk County is obtained from ground water sources. Approximately 60 percent of the county's population is served by over 90 public water supplies; however, some 77,000 homes are dependent upon individual wells for their sole source of water. Since there are only seven limited public sewer districts in the county, over 95 percent of the population depends upon individual or private sewage disposal. Pervious natural sand and gravel formations underlie several feet of top soil and loam throughout most of the county, and private sewage disposal is readily accomplished through leaching cesspools.

The main sources of ground water contamination are domestic sewage and industrial waste effluents returned to the ground water through individual leaching systems. Other sources include cesspool scavenger waste and refuse disposal sites, and storm water recharge sumps.

Domestic and industrial sanitary sewage systems discharge large quantities of raw sewage into the ground waters. Over 150,000 private residences discharge an estimated total of 30 million gallons per day. This does not include substantial discharges resulting from summer residents, or an estimated 2 million gallons per day that is discharged by large institutions and industrial plants. In addition, hundreds of business areas and shopping centers discharge large volumes of domestic sewage to the ground waters and cesspool scavenger sites receive approximately 100,000 gallons of wastes per day.

The problems, encountered in Suffolk County, that have resulted from contamination of ground water by sewage have been primarily restricted to the soluble chemicals. Anionic surfactants, such as alkyl benzene sulfonate (ABS), and nitrogen compounds have appeared in high concentrations in the ground water of the densely populated areas of the county. Over 1000 domestic wells have been found to contain these soluble chemicals in appreciable amounts. Slow filtration through the natural sand and gravel formations has minimized the problem of bacterial pollution associated with private wells when sewage disposal is on individual building plots. Coliform-contaminated water has been found in some such domestic well supplies. The role of viruses in our ground water contamination problem has not been determined.

Mr. Flynn's paper, presented earlier at this Symposium, has aptly detailed our ground water pollution problems in Suffolk County. Comprehensive studies on this subject are available in the literature (1, 2, 3).

The obvious corrective measures for sewage contamination of ground water are the extension of public water supplies to serve private well users in the affected areas and the installation of public sewers and modern treatment plants with outfalls to salt water. The extension of public water supplies to these areas presents a problem. Through concerted efforts by our department, working with the Suffolk County Water Authority and local civic groups, a few of these affected areas have received public water. The procedure for obtaining permission to extend public water supplies is cumbersome and is complicated further by the multiplicity of ownership of the 90 odd public water supplies in the county.

Although Suffolk County has no definite plans for the installation of public sewers, the County Executive has proposed an engineering study for a comprehensive public sewerage plan. Meanwhile, our department has taken legal steps to prevent gross contamination of new private well supplies. Our County Sanitary Code requires that all new wells be at least 100 feet from the nearest sewage disposal system and penetrate at least 40 feet into the water-bearing stratum. In sub-divisions involving five or more building plots, each plot must have a minimum area of 20,000 square feet if private wells are proposed. In every case, private wells are approved only after it has been determined that public water supply cannot be extended or that it is not feasible to form a new public water supply to serve the area. Over 90 percent of all lots approved during 1960 will be served with public water. The few sub-divisions for which private wells are proposed are scattered over the less-populated eastern portion of the county.

The discharge of liquid industrial wastes into the ground waters of the county has received considerable study, resulting in the abatement of pollution and the control of new outlets. Liquid wastes, in particular chromic acid and chromates, from various metal finishing processes were involved in numerous ground water pollution cases in Suffolk County and in neighboring Nassau County. Abatement of ground water pollution from existing untreated liquid industrial waste discharges in Suffolk County was accomplished through field inspections and surveys, including sampling of outlets, by our engineering staff. More than 600 industrial plants were inspected, and all discharges of untreated industrial wastes were eliminated.

Plant officials were called into our office for informal hearing at which the New York State Public Health Law and the Suffolk County Sanitary Code for the treatment of industrial waste effluents were reviewed. The required application and plans for treatment facilities were to be submitted to our department within 90 days. Further, upon receipt of the approved plans, the treatment facilities were required to be constructed and placed in operation within 90 days.

We have been fortunate in obtaining voluntary corrections in almost all cases. Some delays resulted from complicated plant plumbing arrangements or difficulties in determining the type of treatment for the particular wastes involved. In all cases, metallic wastes such as hexavalent chromium must be treated so that the concentrations in the effluents are as close as possible to the U. S. Public Health Service Drinking Water Standards. Follow-up inspections and routine sampling are carried out to assure proper operation of treatment units. Reports of daily operation must be submitted monthly to our office, as an additional control measure.

We have found from bitter experience that it is unwise to depend on any dilution factor in our ground waters. Hexavalent chromium was found to have traveled over a mile from the source of contamination and with concentrations as high as 40 ppm off the plant site (4).

A continuing enforcement problem exists in relation to change of ownership or a change in the operations of an existing industry that results in industrial waste discharges. There is no uniform control procedure except constant vigilance on the part of our district engineers and sanitary inspectors.

New industrial waste discharges are controlled through the N. Y. State Water Pollution Control Law (Article 12 of the Public Health Law) and the Suffolk County Sanitary Code. When daily flows are more than 20,000 gallons, a state permit is required for each discharge. Smaller flows require only County Health Department approval. In all cases, complete treatment of industrial wastes is required. When state approval is necessary, our department acts as the reviewing agency for the State Health Department and Water Pollution Control Board.

Launderette waste disposal has caused a unique problem in Suffolk County. Mr. Flynn presented earlier the details of the ground water contamination problem caused by launderette wastes.

In 1954, following complaints of contaminated private wells in the vicinity of two launderettes in the county, legal action was taken by this department in the form of formal hearings before the Commissioner of Health. These hearings resulted in the closing of the two launderettes (3).

In the county several other launderettes involved in contamination of private water supplies installed water-tight waste collection systems. The liquid wastes were then carted to a town scavenger dump.

In 1956, our efforts to control launderette wastes were expanded. Through the cooperation of most of our Town Boards, the construction and operation of launderettes without prior approval from the County Health Department were prohibited by town ordinances. To obtain approval, it was necessary that the owner of the proposed launderette present plans, by a licensed professional engineer, for a disposal system based on a flow of 400 gallons per machine per day, along with an engineer's report on the status of the water supply in the area of the proposed launderette.

In the areas south of the ground water divide of Suffolk County, the ground water flow is generally in the south-easterly direction; therefore, in these areas, it was required that the study include a strip 500 feet wide and 5000 feet long, extending from the proposed site in the direction of the ground water flow. In areas where the ground water flow was uncertain, it was necessary to include all that area within a 1/2-mile radius of the proposed site.

The survey was required to depict on a map the location of all private wells and public water supply mains within the area. If the area included private or public water supply wells, approval of a leaching disposal system was denied. Only water-tight systems, designed to hold a 2-day flow, were approved in such cases. The wastes had to be transferred by scavenger truck to an approved town dumping site. This is a costly operation (10 to 20 cents per wash load), and very few prospective launderette owners elected to install such systems.

Since completion of the Water Pollution Control Board's research project on the effect of synthetic detergents on our ground waters, which was conducted by C. W. Lauman Company in cooperation with the Suffolk County Health Department in June 1960 (3), no approvals have been granted for waste disposal systems for launderettes. This restriction on launderettes was necessary because of the obvious ground water pollution resulting from their wastes, particularly the ABS content. We are now awaiting a satisfactory plan for the treatment of launderette wastes. The criteria for such treatment are the removal of a substantial portion of dissolved solids (including ABS), suspended solids, and any other substances that contribute to water taste problems.

There has been considerable activity between launderette manufacturers and water and waste disposal equipment manufacturers, which should result in the submission of treatment units in the near future. We will accept one installation of each promising type of treatment unit on an experimental basis. After several months of evaluation, we will accept or reject the treatment unit. If acceptable, then any new launderettes proposing the same type of treatment would be approved. Also, in June 1960, operation of the existing 102 launderettes in the county were notified that they must have installed approved waste treatment facilities by June 1, 1961, or legal action will be initiated against them by this department. This deadline will have to be extended to await development of one or more acceptable treatment processes for launderette wastes.

The ground water contamination problems resulting from cesspool scavenger waste and refuse disposal sites have never been thoroughly evaluated. The scavenger waste problem would be solved by a county sewerage system. In the absence of such a sewerage system, these wastes are largely disposed of at sites used for garbage and refuse disposal. The ground waters in these immediate vicinities undoubtedly are grossly contaminated; however, such sites are few and are generally located on large parcels of town-owned land.

The 400 odd storm water recharge basins in the county receive a daily discharge averaging 10 million gallons. The role of these recharge basins in both water conservation and disposal of storm water is unquestioned. Water entering these basins contains cumulative quantities of chemicals used as insecticides and herbicides on lawns and gardens, and road surfacing materials. No thorough evaluation has been made of the quality of ground water downstream from these basins. We however, advise, that public water supply sources be located as far as possible, at least 500 feet, from such basins.

Our future control measures depend primarily upon the establishment of a comprehensive public sewerage plan. When such a plan becomes a reality, we will then be able to completely re-evaluate our subdivision requirements for sewage disposal. New sub-divisions can be required to install either "dry sewers" or complete sewerage systems with compact treatment plants. "Dry" lateral sewers would be designed to tie in with the truck sewer system of a comprehensive plan; the small compact treatment plants could be converted to pumping stations for eventual discharge to these truck sewers.

REFERENCES

1. Flynn, J. M., et al. Study of Synthetic Detergents in Ground Water. Journal American Water Works Association, 50:12, 1551-1562. 1958.

2. Davids, H. W. and Flynn, J. M. A Study of Ground Water Quality and Contamination Sources. Public Works, 6:115-117. 1960.

3. Effect of Synthetic Detergents on Ground Water of Long Island, New York. Research Report No. 6, New York State Water Pollution Control Board. 1960.

4. Davids, H. W. and Lieber, M. Underground Water Contamination by Chromium Wastes. Water & Sewage Works, 12:526-534. 1951.

CONTAMINATED GROUND WATER AND HOUSING

J. A. McCullough, Federal Housing Administration

The chief purposes for which FHA was created are to encourage improvement in housing standards and conditions, to facilitate sound home financing on reasonable terms, and to exert a stabilizing influence in the mortgage market. Policy, rules, regulations, standards, etc., have been developed to assure that these purposes will be accomplished.

Each living unit that is to serve as security for mortgage insurance must be provided with a continuing and sufficient supply of safe and palatable water under adequate pressure. Whenever feasible, connection to a satisfactory public water system is required. Even though an adequate public water supply line is not adjacent to the tract, connection will be required wherever it is feasible to have the service extended to serve the tract. If it is not feasible to obtain service from a public water supply system, then consideration is to be given to the feasibility of obtaining service from a properly designed, constructed, organized, and operated community system. Only after it has been determined that service from an acceptable public or community water system is not available or feasible and that ground water and subsurface conditions are found to be satisfactory may service from individual systems be considered.

Careful architectural, engineering, and valuation analyses are made of all proposals - either proposals for new construction or existing construction. In the proposed construction category, there are three definite stages in the erection of a house where a trained construction inspector observes the work to determine whether it is in compliance with the previously approved plans. Where existing construction is involved, a Valuator examines the property from all viewpoints for the purpose of determining its value. The type of water supply system and the quality of water available are always taken into consideration. All of this is done to determine that the risk involved with insuring a property is at an acceptable level.

It is our belief that if a house is well planned, properly located, and constructed of sound materials, it will give long satisfactory service to the owner and have a continuing strong appeal in the market, provided it is given reasonable maintenance. We are constantly watching for things that may result in abnormal expenses to an owner because we know this is a contributing factor to dissatisfaction with a property, to loss of value, and reduced desirability.

For this meeting, a few of the effects contaminated ground water can have on a property using it as a source of domestic water supply will be considered. Ground water so heavily contaminated that bacteriological examinations of samples give positive readings presents no problem in reaching a conclusion. Such water is not safe for use and no prudent prospective home buyer who is aware of the situation would consider purchasing a house served by it. Acceptance of such a property by FHA would not be in keeping with "improvement in housing standards and conditions."

What about property served by a water source that is exhibiting indications of contamination but the level of concentration has not yet reached the point where it can be classified as "dangerous" or "unsafe," etc., in accordance with public health practice? FHA puts forth a great amount of effort to try to foresee what the conditions might be in the future insofar as such a source of water supply is concerned. We have sanitary engineers stationed across the country to assist and guide our field offices in making determinations under such conditions. They work closely with Federal, State, and local health authorities and with State and Federal geological personnel in gathering data that bear on this problem.

ABS, or detergent, is one chemical compound that when detected in ground water is evidence of contamination. At the moment none of us know what effect this material has or will have on the consumer. We don't know whether it is detrimental or beneficial, whether it will affect old persons and not the young, or vice versa. We do know, however, that as the concentration approaches 1 ppm, the water becomes undesirable because of taste and odor. Through the experiences of our field sanitary engineers we have accumulated a considerable amount of knowledge of the problems home owners face when they are receiving water from contaminated ground water strata. The time between completion of the house and occupancy and the first detectable signs of taste or the appearance of frothy water at the taps varies from a few months to several years. There are many contributing factors. We believe however that once even a trace of detergent is detected in the water, even though it is only detectable by laboratory analysis, it is just a matter of time until the concentration increases to a level at which the water is no longer acceptable. The home owner's only recourse is to spend money to obtain acceptable water. In one instance the only satisfactory water available was that sold by the gallon by the local milk delivery man. Permanent correction requires money and time. The amounts of both vary with the circumstances.

We must consider the plight of the homeowner who wants to sell his home under these conditions. If the available water is contaminated and a permanent solution has not materialized, he probably cannot sell his home; or if he does, he may suffer a loss because of reduced desirability and market appeal.

Determining whether ground water and subsurface conditions are satisfactory and that safe and palatable water will continue to be available under conditions of dense development, immediately under as well as in the general vicinity of a proposed subdivision, is one of our most important and difficult tasks. The new products of present day technology and the never-ending search for new and better ways to do things is complicating our task. Many new chemical products are being used on the ground for a variety of purposes. Some are finding their way into the ground water strata. Those products for which toxicity limits have not been established further complicate our task.

Every effort is made to avoid getting a prospective home owner involved, through the medium of mortgage insurance, with a property that after a few years of occupancy might develop a major defect, such as contaminated drinking water, and then not be eligible for re-insurance. FHA and its procedures operate for the protection of the home owner and the lender.

THE WAY WE DO IT!

R. V. Stone, Jr., Santa Ana Regional
Water Pollution Control Board, California

Water pollution control in California is the responsibility of a State Board and nine regional boards. Each regional board serves one of the nine main watersheds of the State. To understand the regional concept of the California Water Pollution Control Act, one must first have some knowledge of the State, particularly its population, water supply, and geography.

Along its coast California extends approximately 1000 miles from north latitude 32°27'36" at the Mexican border to north latitude 42°00'00" at the Oregon state line. Its nearly 16,000,000 population is distributed 30 percent in the north and 70 percent in the south. The water resources of the State, however, are distributed 70 percent in the north and only 30 percent in the south. It is this imbalance that makes necessary the importation of water into southern California from Owens Valley, the Colorado River, and the now planned Feather River Project of the California Water Plan. Furthermore, the climate and rainfall vary greatly. The north is generally colder than the south and receives considerably more rain and snow. Water supplies in the north are derived from surface streams, whereas local water supplies in the south come from ground water basins.

Seven of the nine regions drain into the Pacific Ocean. The ocean ultimately receives land drainage, including wastes, from these regions. Although the ocean is big and generally has the same physical and chemical properties along the coast, its uses differ greatly. In the Humbolt Bay area of the north, the weather is cold and recreation involving body and water contact in the bay and ocean may be measured in days during any year. At the other extreme, water-contact uses in Santa Monica Bay, with but few exceptions, occur daily.

In summary, the State may be divided through its middle into the northern and southern halves. The north is colder, wetter, and less populated than the south. Except for the San Francisco Bay area, which imports the major portion of its water, the north takes its water supply from local surface sources. The south takes its local supply from ground water basins and also imports water to meet its needs. As previously shown, regional uses of the ocean differ greatly.

Water quality is another variable somewhat dependent on locale. Northern surface supplies generally are low in total dissolved minerals and are soft. Because of the more arid climate, southern water supplies are generally more mineralized. The imported surface supply from the Colorado River at present contains more than a ton of dissolved minerals per acre foot (700 - 800 mg/l). The water is being put to beneficial uses, and its users are pleased to have the water. In the north, however, water with this same quality would be considered a waste water rather than a water supply.

Because of the many variables between the watersheds of the State, uniform State standards would be most difficult or even impossible to adopt and enforce. The water pollution control board within each respective region provides the protection needed for the water users. In each region the discharger receives water pollution control requirements from the regional board. These requirements may be for discharge water or for receiving waters or for a combination of the two. The manner in which the discharger meets the requirements is his decision, since the law prohibits the boards from specifying the design or process to be used. Discharges may be prohibited, however, at specific locations.

Technology

In our present day civilization, the sanitary engineer and his allied workers have studied, designed, built, and operated water purification and waste disposal facilities. The theory involved and the processes employed have resulted from the needs of improving the public health and eliminating nuisances and unsightliness. Today waterborne gastrointestinal deseases are controlled, lead water pipes that caused lead poisoning have been eliminated, and nuisances have been abated to protect the aesthetic pleasures.

Waste disposal and water purification techniques are employed to reduce and eliminate pathogenic bacteria, taste and odors, turbidity and particulates, to restore and maintain oxygen balances in the receiving stream, to reduce and stabilize organic substances that would create sludge deposits, to demineralize and soften water, and to eliminate or remove poisonous and radioactive materials. In the arid part of California and elsewhere in the State where wastes are treated by conventional methods, the total dissolved minerals in ground water supplies are increasing. Factors that influence ground water quality are consumptive water uses, rainfall, and waters returned from irrigation and from municipal and industrial wastes. The increases in mineral concentrations in the underground basins are the result of increased losses of water through evaporation and transpiration and salt additions to water used agriculturally, municipally, or industrially, and partially the result of reduced transport of water through the basin as a consequence of less than normal rainfall during the past 10 to 15 years. These phenomena cause an adverse salt balance within a ground water basin. Such adverse salt balance threatens and eventually will cause pollution of the ground water supply. It is the treatment or handling, or both treatment and handling, of dissolved substances in wastes that falls within what I term the technological vacuum. In the past, except for poisonous, radioactive, phenolic, and alkyl benzene sulfonate compounds, very little emphasis has been placed on the chemical quality control of wastes or receiving waters. Technologically, the processes that will economically bring about these controls have not been developed or are unknown. This conference is the first indication that there is a national interest in water quality control techniques. With concentrated interest and work in this field, we can, figuratively, look forward to a cornucopia of knowledge rather than retention of the present vacuum.

Enforcement

The Water Pollution Control Act established legal procedures for enforcing requirements set by the Boards. Contingent upon the severity and nature of the pollution, the law provides for summary abatement or injunction against the discharger. Although the legal enforcement procedures apply uniformly throughout the State, the type of requirements set by the different boards and the methods for checking for compliance differ from region to region. So that enforcement, "the way we do it," in California can be described, the various regions have been canvassed for their procedures and policies. The discussion of the procedures and policies will not make reference to the individual regions, since the information is a compilation of all the ways we do it.

Within most watersheds with ground water basins there is a network system of water-connected subsurface streams and reservoirs. Generally, the forebay or recharge area for a network is near the mountains or foothills. As water moves downstream through the network, its mineral load increases and its quality is considered to decrease. The farthest downstream user therefore is the captive recipient of all that goes before. Regulation of the rate of quality degradation, as the ground water stream flows from sub-basin to sub-basin, requires the formulation and adoption of water quality objectives. Objectives are a declaration of policy setting goals or ideals that will permit the orderly use and reuse of the ground waters and at the same time afford protection to the lowest man on the totem pole, the downstream user.

The limits adopted in ground water objectives are checked by collection and analysis of ground water samples from wells specifically selected to give representative data on the underground stream as it leaves a particular zone or sub-basin. These wells are called monitoring wells, for checking water quality objectives. By use of a system of monitoring wells and routine chemical analyses of samples collected on a regular schedule, the water quality for any period may be compared with that from other periods. Through a program of such data collection, chemical changes with respect to time will be available from the records.

The maintenance of water quality objectives within the limits set is dependent upon waste discharge requirements or receiving water requirements. When wastes are discharged onto the ground or into seepage pits, they percolate down to the ground water table and become part of the ground water stream. The physiochemical phenomena exerted on and reacting with these wastes are variable and for the most part indeterminate. For instance, the soil above the ground water table has a holding or storage capacity and it is in this zone that capillary action, evapotranspiration, ion exchange, chemical reaction, and precipitation, individually or in combination, may alter the percolating wastes or even remove them from the system.

The path taken by percolating wastes after they reach the ground water table has been the subject of considerable speculation and debate. Some argue that the percolate virtually remains on the free water surface with some slight vertical diffusion or mixing as it moves downstream with the main ground water body. Others believe that gravity and turbulence cause the heavier percolate to mix rapidly with the moving ground water stream.

All of these variables make difficult a rational analysis of what a particular waste will do to a particular ground water system. Unless there has been experience with wastes that have affected the ground water within a specific area, requirements for waste discharges must be based on judgment rather than on facts. Such arbitrary limits have been set on some of the discharges in the State.

Another approach to pollution control is the setting of limits on the receiving waters. Absolute maxima may be adopted for the ground water downstream form a discharge. This appears to be a straightforward approach; however, a single upstream discharge of waste can so change the ground water quality that the water would have no capacity to dilute wastes added by a downstream discharger. Rationing of the assimilative capacity of the ground water stream is possible by the establishing of stepwise accumulative limits of degradation in the downstream direction. The success of this procedure, like that of the first, would depend heavily upon judgment.

An incremental increase concept has been employed to regulate wastes. According to this concept, based on a domestic use of water, the mineral content of water through use by a municipality will increase by certain increments. Studies have been made, and average increments for the several chemical constituents have been determined. These incremental increases are not reduced by waste treatment processes presently employed. Comparatively, an industrial use of water is considered equivalent to a domestic use when the incremental increase in the chemical constituents are equivalent. If a domestic use of water is considered a reasonable use, the equivalent industrial use also would be considered reasonable use.

When requirements, based on one or a combination of several of the above principles, are set for pollution control, the basis for satisfactory compliance also must be described. Compliance within fixed limits set by requirements may be determined from each waste analysis or from an average of several analyses, perhaps weighted in accordance with flow, or from a combination of average values and specific extremes.

When requirements are set on the receiving waters, monitoring wells must be employed. For absolute limits in the ground water quality downstream from a discharge, only downstream monitoring wells need be used. Compliance can be based on individual samples from individual wells or average values from several wells during any stated sampling period.

Compliance checking for incremental chemical increases in the ground water requires that several monitoring wells be used. At least one upstream well and one downstream well are needed, and more are preferred. Here again compliance may be based on individual results or averages, or both.

Our enforcement program employs both the setting of requirements for water pollution control and compliance checking to see that the requirements are met. The requirements include one or more of the following restrictions: maximum - minimum limits on the waste discharge, incremental increases between the water supply and waste discharge, maximum - minimum limits on the ground water, or incremental increases between upstream and downstream sampling points in the ground water basin.

Compliance with requirements is based on individual techniques or on a combination of techniques including waste analyses, or ground water analyses. Individual results or average conditions, or both may be specified for compliance with the limiting values.

Technical Reports

In addition to the enforcement techniques now employed, many of the dischargers are required to sample and analyze their wastes on a prescribed schedule. These data and records of flow are submitted to the boards as technical reports. The Water Pollution Control Act gives the boards the authority to require such technical reports.

The information from these technical reports and the data obtained from monitoring wells, studied one in the light of the order, give a cause and effect analysis of changes in water quality.

Critique

A critical review of the way we control ground water pollution reveals loopholes and shortcomings. Arbitrary limits based on our present inadequate knowledge of the underground phenomena can have a serious and adverse effect on a community. Very strict limits would so restrain a community that its normal growth would be materially altered, or operating costs of an industry might be so increased that its product could not compete with those from another area. On the other hand, liberal limits would not afford protection to the ground water basin. It is the middle ground, somewhere between liberal and strict limits, that will allow community growth and fair industrial competition, without creating the threat of pollution, a threat difficult to determine.

The use of incremental increases, arbitrary or based on a domestic use of water, is subject to the argument of how much if any pollutant a discharger is entitled to discharge.

As we gain experience and obtain knowledge through research, I envision that the ideal requirements for waste discharges will be based on the following: absolute maximum - minimum limits on the waste, absolute maximum - minimum limits on the downstream ground waters, and average conditions limited by increments between upstream and downstream ground water quality. Data collection for compliance checking will include water analyses, flow measurements, and analyses of ground water sampled from monitoring wells.

THE QUESTION

The title of this paper "The Way We Do It?" is posed as a question. I have presented the how and why we do it in California, but I question that ours is the only or best way to do it. By comparison of other work with the way we do it, I am convinced that better ways to manage and enforce ground water quality will evolve. Until we learn of these better ways, our present policies will be continued. Furthermore, these policies have been successful, since nowhere in the State is there a major problem of ground water pollution from sewage or industrial wastes.

We have experienced sporadic local problems such as the chlorinated phenols involved in the "Montebello incident," hexavalent chromium at Murrietta Hot Springs, and alkyl benzene sulfonate at Barstow and San Bernardino. All of these conditions have been or are being corrected.

It certainly has been my pleasure to attend this conference and to share experiences. When I return home, I expect to take with me your suggestions and recommendations from which we may amend our way.

DISCUSSION 4

Chairman: Murray Stein

Mr. C. S. Wilson asked Mr. O. J. Muegge whether the spacing between wells and septic tanks required by Wisconsin regulations depends entirely on distance or may the regulatory agency refuse a permit on some other basis. Mr. Muegge answered that in the first place the State does not issue permits; however, he stated further that the spacing distance quoted (50 feet) is the absolute minimum and that the distance must be as great as possible.

Professor R. H. Bogan addressed the following general question to the group. Since the Federal Housing Administration uses a maximum allowable concentration of ABS to determine the safety of domestic well water, is ABS considered an indicator of general pollution and, if not, would they welcome an indicator of general pollution? Mr. R. H. Baker of Florida said that their position, which also had been indicated to the FHA, was that they would prefer not having mortgages insured unless the property had community water and sewerage available. Mr. F. L. Woodward pointed out that the limits used by FHA applied only to the Minneapolis-St. Paul area. Mr. J. A. McCullough of the FHA stated that the standard applied only to the Twin City area. He also stated that they used 0.2 ppm ABS and that he would discuss this in his paper (see McCullough's paper). The requirements were set with the assistance of Mr. Woodward and the Minnesota State Department of Health. They are based on background information on the basic ground water quality in the area. Mr. McCullough further stated that this is in line with the general FHA requirements - a property eligible for mortgage insurance must have a continuing and satisfactory supply of safe and palatable water. They depend on the Health Departments in determining this factor. If the State or local authority indicates the water is not safe, the FHA accepts their decision.

Mr. Muegge indicated that he is not sure about the validity of using 1 ppm NO_3-N as an indicator, because he has seen concentrations greater than this in uncontaminated artesian wells. He said, however, he thinks 35 to 50 ppm is too high; he recalled one case of methemoglobinemia that had occurred after use of water with 11 ppm NO_3-N.

Dr. Richard L. Woodward asked Mr. Davids whether, in connection with the launderette problem, any consideration had been given to asking the launderettes to shift to use of zero hardness water and use of soap instead of detergents. Mr. Davids answered that this had been proposed but the owners believed they could not control the type of washing compound used in the laundries. These laundries are coin-operated, and since often no attendant is on duty, control of the individual user would seem next to impossible. The water in the area is already of a low hardness, approximately 20 to 30 ppm. Dr. Woodward then asked Mr. R. V. Stone, Jr., whether the Santa Ana Regional Water Pollution Control Board can predict the direction of ground water flow accurately enough that they can locate one or a few wells to monitor successfully ground water quality changes. Mr. Stone gave a qualified "yes" answer. He pointed out that the Department of Water Resources personnel have detailed information on ground water conditions within the region and that they are confident that monitoring wells will detect ground water quality changes. He indicated that occasionally there are aggregate effects of ground water contamination arising from several sources, making it difficult to pinpoint a single source. In such cases the technical reports, required of each discharger, show the quantity and characteristics of each waste and thus prove helpful.

Mr. Baker of Florida asked Mr. McCullough whether he could explain further how FHA determines whether community water and sewage systems are "feasible." He also asked whether consideration has been given to insuring loans for financing subdivision water and sewerage systems. Mr. McCullough answered the latter question first, indicating that FHA has been attempting to secure legislation that would allow them to insure loans for such community systems. In answering the first question, Mr. McCullough indicated that the FHA prefers types of sewage disposal systems in the following order: existing municipal sewerage systems, other publicly controlled sewerage systems, and last of all on-lot sewage disposal systems. The feasibility of obtaining one of the first two methods is primarily an economic problem, depending on the amount of land under control of the developer, the cost of septic tanks versus that of other types of sewage disposal, the amount of revenue available for operation of the sewerage system, the possibility of stage construction, etc. Mr. Baker again commented that if we concede that utilities can produce revenue and can be profitable why not require community water and sewerage; however, he recognized that the big problem is obtaining the money to build plants. Mr. McCullough agreed and again indicated that the FHA would like to have the power to insure such financing.

Mr. W. K. Hess asked why, since it has been indicated during the Symposium that reuse of water may be a necessity, there is this tendency to condemn the use of ground water and private wells. He suggested that rather than condemn the use of ground water regulation might be directed toward greater protection of the ground water through increased use of municipal sewerage systems. Referring to the Minnesota minimum of 1 ppm of nitrate-nitrogen and the opposition to this regulation by economic interests, Mr. Hess pointed out that opposition is bound to come from groups whose livelihood is deeply involved and that they also know something about these problems. He pointed out the need for better understanding of the magnitude of these economic interests.

SESSION 5

RESEARCH ON GROUND WATER CONTAMINATION

Chairman: B. B. Berger

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Sewage Reclamation by Pressurized Recharge of Aquifers, J. E. McKee and W. R. Samples . . . . Page 186

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RETENTION OF ABS ON SOILS AND BIOLOGICAL SLIMES

B. B. Ewing, L. W. Lefke, and S. K. Banerji,
University of Illinois

The purpose of a research project conducted over the past year at the Sanitary Engineering Laboratory of the University of Illinois has been to determine what mechanisms may be important in retarding the movement of alkyl benzene sulfonate in ground waters. A satisfactory method of studying retention of ABS on soils and biological slimes has been developed by modification of existing procedures using a radioisotope of sulfur. The physical adsorption of ABS on a coarse sand is very low, but does follow the Freundlich isotherm reasonably well. Adsorption is time dependent, and column conditions yield lower adsorption than batch studies at the same ABS concentration. At an ABS concentration of 50 mg/1, Ottawa sand in a column was found to retain only 3.30 μg of ABS per gram of sand. Even so, the relative velocity of the ABS front with respect to the water front under these conditions would be 0.77. When a biological slime was developed on the sand in a similar column, seven times as much ABS was retained in the solid phase. Under these conditions, the relative velocity of the ABS front would be 0.31. It has not been determined to what extent this increased retention is due to the large surface area provided by the microbial cells. The biological slime grown on sewage in the first few feet of soil under a septic tank drain field, under a sewage oxidation pond, or under a polluted stream might retard the movement of ABS for a time. Beyond the first few feet, where slime growth would be negligible, retention of ABS would be due principally to physical adsorption on the soil, and this effect would not be great for coarse clean sand.

INTRODUCTION

The use of synthetic detergents for both domestic and industrial purposes has increased greatly since they became generally available on the market soon after the second World War. At the present time, it is estimated that each householder uses and discharges to the environment about 100 pounds of synthetic detergent annually (1).

The first reports of syndets in waste having any detrimental effects came from sewage treatment plants, where they were suspected of causing foaming. Later they were reported to affect surface waters and to interfere with some water treatment processes and to cause consumer complaints of foaming and an off-taste of drinking water.

Ground Water Pollution

Although their use has been general in the United States since 1948 and synthetic detergents have been discharged to the aqueous environment in increasing amounts since that time, there were no published reports of major ground water contamination until 1958 (1). The first reported incident involved housing developments on Long Island, N. Y., in which each lot was provided a shallow well for water supply and a cesspool for sewage disposal. Since then, there have been reports of similar ground water pollution in metropolitan fringe areas in 13 states (2). Serious problems have been encountered in the Minneapolis-St. Paul area (2), Suffolk County, Long Island (1), and Portsmouth, Rhode Island (3). There have also been incidents of pollution of ground water from polluted streams, sewage oxidation ponds, and holding ponds for industrial waste. It is obvious that, whereas the adverse effect synthetic detergents have on ground waters was not recognized as early as in the case of surface waters and waste waters, the problem is real. What makes it even more serious is that ground water pollution is of long duration even though the source of the pollution is removed.

Synthetic detergents being marketed today contain a variety of ingredients, including surface active agents, phosphate builders, and miscellaneous builders (4). The surface active agents most commonly used are anionic compounds and are usually of the class of compounds called alkyl benzene sulfonate (ABS). These surfactants in concentrations greater than 0.5 mg/l cause foaming in water (3). Flynn et al.(1) showed that "off-taste" complaints are encountered when water contains more than 1.5 mg/l surfactant (as ABS), although it is possible that the taste is caused instead by the builder compounds associated with this amount of ABS in the packaged product. Toxicity studies on humans and other animals indicate the toxicity of ABS is so low as to cause no effect in man at concentrations likely to be encountered in drinking water (5). Although present Public Health Service Drinking Water Standards (6) impose no limit on the concentration of ABS in drinking water, it has been proposed that the standards be revised to incorporate a recommended limit of ABS concentration of 0.5 mg/l in drinking water (7). This recommendation is based on the aesthetic effect.

Underground Movement of Syndets

A review of the technical literature indicates that the distance traveled by ABS in ground water, although generally short, in some instances may be fairly great. Flynn et al. (1) reported no ABS found in wells more than 65 feet from the source of pollution. They also showed that the probability of finding syndets in water from wells decreased as the depth of the well increased. The ground water in the area travels 1 to 3 feet per day. Chromium wastes from a plating plant that had been in operation for 2-1/2 years were found to have traveled about 1200 feet, which corresponds to 1.3 feet per day. Inasmuch as the detergents, which must have been used in increasing amounts over the past 10 years, had only traveled 65 feet, it appears there is some mechanism by which the movement of ABS is retarded.

A recent study of pollution of ground water on Long Island by launderette waste (8) showed that at Mastic, New York, ABS has traveled an over-all distance of 1100 feet downstream from a launderette. If the ground water traveled 1 to 3 feet per day, this distance would be traversed in 1 to 3 years. The launderette had been in operation for 12 years, however.

Walton (2) showed that in almost every instance wells contaminated with ABS by household sewage disposal systems were less than 100 feet from the source of pollution. On the other hand, he cited reports that in five instances ABS had been found more than 1000 feet from the source of pollution, where the source was a municipal or industrial waste pond or recharge pit.

It is concluded that the distance traveled by ABS depends upon many factors, one of which appears to be the amount of ABS introduced into the soil at the source. Greater area would be contaminated by municipal and industrial waste disposal facilities than by individual household facilities. This fact, together with the comparison between distance traveled by the ground water and distance traveled by the ABS on Long Island, leads to the conclusion that the porous medium through which ground water flows has some capacity to retain ABS and to retard the movement of ABS in the water phase.

Mechanism of Retardation

Movement of a pollute through a ground water formation is a displacement process. The vehicle of transportation of synthetic detergents is waste-contaminated ground water. The pollute moves into a zone of earth, and until the zone has retained an amount of pollute equal to its capacity, the pollute is retained. When the zone has retained its capacity, pollute in the pore fluid is displaced by continued flow of waste water into a new zone. There is always, then, a fringe of earth material that is being loaded with the pollute. The pollute moves as a diffuse front through the formation. The width of the front depends upon the kinetics involved in the mechanism representing the capacity of the soil to retain pollute and the hydraulic dispersion phenomena in ground water flow.

The mean velocity of movement of a pollute front may be expressed as:

$$S = \frac{C\,vf}{R} \qquad (1)$$

where S is the velocity of the pollute front in feet (or meters) per day, R is the retention capacity per unit gross volume of earth for the pollute in micrograms per cubic centimeter, C is the concentration of the pollute in the feed solution or waste water at the source in milligrams per liter, and v is the average velocity of the transporting water at the same point in the earth in feet (or meters) per day, and f is the porosity. Also, vf is the discharge per unit cross-sectional area at this point. Hence, the velocity of the pollute front is inversely proportional to the capacity of the formation to retain the pollute and directly proportional to the concentration of pollute in waste water and the percolation rate.

The retentive capacity would never be less than the amount of pollute contained in the amount of waste water required to displace the pore volume. This would be the product of the concentration of pollute in the waste water and the porosity of the earth, Cf. Substituting this value for R in equation (1) yields S = v. Under these conditions the pollute moves with the percolating water and it is not retarded. Such a pollute would be an ideal tracer of ground water, if it met other conditions of detectability and stability. Actually, the number of substances that fit in this category are not so great as one might suppose. It is more likely that some mechanism would increase the retentive capacity of the formation.

It would appear that the mechanism most probably responsible for retention of anionic surfactants is physical adsorption on the soil. Whereas soils, particularly the clay fraction, exhibit some cation-exchange capacity, their anion-exchange capacity is practically nonexistent. Further, the ABS is soluble in the low concentrations found in waste water, particularly when diluted by ground water. Adsorption, however, might account for considerably more retentive capacity than the pore volume of the formation, in view of the very low concentration of these substances in the transporting water.

Renn and Barada (9) investigated the use of various common adsorbents for removal of ABS from water supplies. Whereas mineral adsorbents were less effective than hydrocarbon-adsorbing surfaces, they did adsorb measureable amounts of ABS. These studies showed suspended silt could adsorb 20 to 50 mg of ABS per gram of silt. For clay, talc, diatomite, silica, and calcium carbonate, the adsorption was in the order of magnitude of 1 mg of ABS per gram of material.

The retentive capacity of the solid phase for adsorption of a pollute is generally expressed as the weight of adsorbate, X, per unit weight of adsorbent, M. The solid phase retentive capacity would be X/M times ρ, the bulk density of the earth material. The total retention would be the sum of the pollute stored on the solid phase and that stored in the liquid phase:

$$R = Cf + \frac{X}{M}\rho \qquad (2)$$

Substitution in equation (1) yields an expression for the relative velocity of the pollute front:

$$S/v = \frac{1}{1 + \left(\frac{X/M\rho}{Cf}\right)} \qquad (3)$$

$$\text{or} \qquad S/v = \frac{1}{1 + D} \qquad (3a)$$

where D is a distribution factor equal to the ratio of pollute on the solid phase to that in the liquid phase. Thus, the rate of movement of a pollute is dependent on the distribution factor and the percolation rate of the transporting water.

The amount of pollute adsorbed on the solid phase will increase until it equals the specific adsorption capacity in equilibrium with the concentration of the pollute in the liquid phase. According to the Freundlich isotherm, the equilibrium is expressed as:

$$X/M = KC^{1/n} \qquad (4)$$

where k and n are constants. Accordingly, a study of the characteristics of the adsorption isotherm for ABS on some typical earth materials seems to be worthwhile in making predictions regarding the movement of ABS in ground water.

Undoubtedly absorption on the surface of soil particles is an important mechanism in retarding the movement of ABS, but under some conditions the development of a zoogleal slime on the soil particles may cause further loss of ABS. The large surface area provided by microbial cells may well offer considerable adsorptive capacity for ABS. In addition, it is known that there is some bacterial decomposition of ABS. Many investigators have studied the biological degradation of ABS in order to determine its fate in biological waste treatment plants (10, 11, 12). They have shown that the decomposition of ABS is slow; even in the intensively active biological systems encountered in trickling filters and activated sludge plants only about half the ABS is decomposed. Nevertheless, the time available for decomposition is much greater in the soil, and in the first few feet of a soil percolation system, it may be that a significant fraction of the ABS is actually decomposed. This phenomena might be important in septic tank percolation fields, sewage oxidation ponds, holding ponds for industrial waste, and ground water recharge operations where the water medium contains sufficient organic matter to support the growth of biological slime. It is important, therefore, that the relative magnitude of ABS decomposition, adsorption on the surface of microbial cells, and adsorption on the soil matrix, and possibly other phenomena be evaluated.

Objectives of Present Study

The objectives of this study are twofold: (1) to determine the relative importance of biological slime activity and physical adsorption in retarding the movement of ABS through a soil system and (2) to evaluate the effect of various parameters on the physical adsorption of ABS on typical water-bearing earth materials.

LABORATORY TECHNIQUES

Retention of ABS on soils and on biological slimes has been determined in the laboratory by deduction of the quantity of ABS in the liquid after contact with the solid phase from the amount originally present. This has been done by both batch and continuous-flow column techniques.

ABS Determination

For the most part determination of the ABS concentration has been by radioassay of ABS labeled with sulfur-35 (ABS^{35}). The specific activity of the labeled ABS was determined initially by the methylene blue method in accordance with Standard Methods, 11th Edition (13). Thereafter, the ABS content of liquid samples was determined by counting the beta activity in an internal proportional counter. Where biological degradation was not considered to be significant, the sulfur-35 was assumed to be associated entirely with the ABS and the total beta activity was used as a measure of the ABS. A 2-ml aliquot of the sample was evaporated in a planchet and counted in the proportional counter. The count was corrected for background, self-absorption, and decay. Since the fraction of ABS adsorbed was sought, relative counting was employed by the same technique used for feed solution of known ABS concentration and for unknown samples. The counting efficiency was therefore the same in both instances.

For special studies, the radioassay technique used by McGauhey et al. (14) has been modified. This procedure permits separate determination of the ABS, the inorganic sulfur produced by degradation of ABS, and the intermediate degradation products. The ABS is separated from the water sample by liquid-liquid extraction with ether. It is then adsorbed on activated carbon. The ether is evaporated; the carbon is resuspended in acetone and water. The carbon is then transferred to a planchet, dried, and counted for radioactivity. The inorganic sulfur remaining in the aqueous portion is oxidized by bromine water, and the sulfate is recovered by barium chloride precipitation and filtration for counting in the proportional counter. The remaining intermediate products, which are not ether-soluble or precipitated as the sulfate, were determined by drying an aliquot of the filtrate in a planchet and counting. The principal modification in the procedure developed by this study has been in the method of transferring the activated carbon to the planchets. Transfer by pipette before evaporation of the acetone-water medium has proved easier than the method used by McGauhey et al. (14) and gave more reproducible results.

Batch Studies

The adsorption of ABS on earth materials has been studied by batch methods in which a small amount of earth is added to 50 or 100 ml of ABS solution in a 150 ml bottle. The mixture is shaken for a measured interval. The earth and solution are separated by settling or, in case of fine soils, by centrifuging and/or filtering. An aliquot of the supernatant liquid is assayed for radioactivity and compared with the original ABS solution. The difference in ABS concentration between supernatant liquid and the original solution is attributed to adsorption on the earth

FIGURE 1. PHOTOGRAPH OF COLUMNS A AND B, SHOWING BIOLOGICAL GROWTH IN COLUMN A

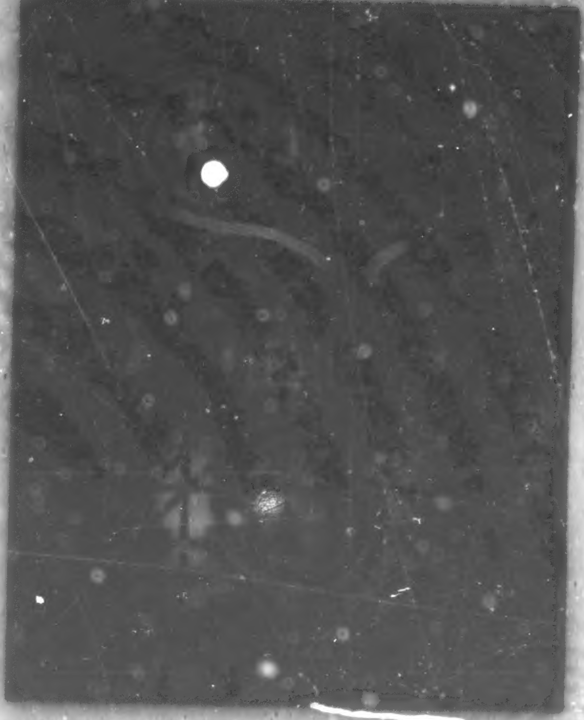

FIGURE 2. PHOTOGRAPH OF COLUMNS C THROUGH F, SHOWING COLUMNS BEFORE SEEDING

Column Preparation

Six earth columns have been prepared for laboratory study of ABS adsorption and biological degradation. The columns consist of sand packed in Pyrex glass pipe 2 inches in diameter. Each column consists of two 18-inch sections so that the column is 36 inches long. This feature permits separation into two lengths that will fit into an autoclave for sterilization. Figures 1 and 2 are photographs of the columns.

The material in the columns is a silica sand of very uniform grain size, a geometric mean of 0.838 mm. The sand was packed in the column dry and then the pore volume was filled with distilled water by the admittance of water at one end while a vacuum was applied to the other end. This prevented air-binding. The pore volume was determined by displacement of the pore fluid with a chloride solution. The chloride break-

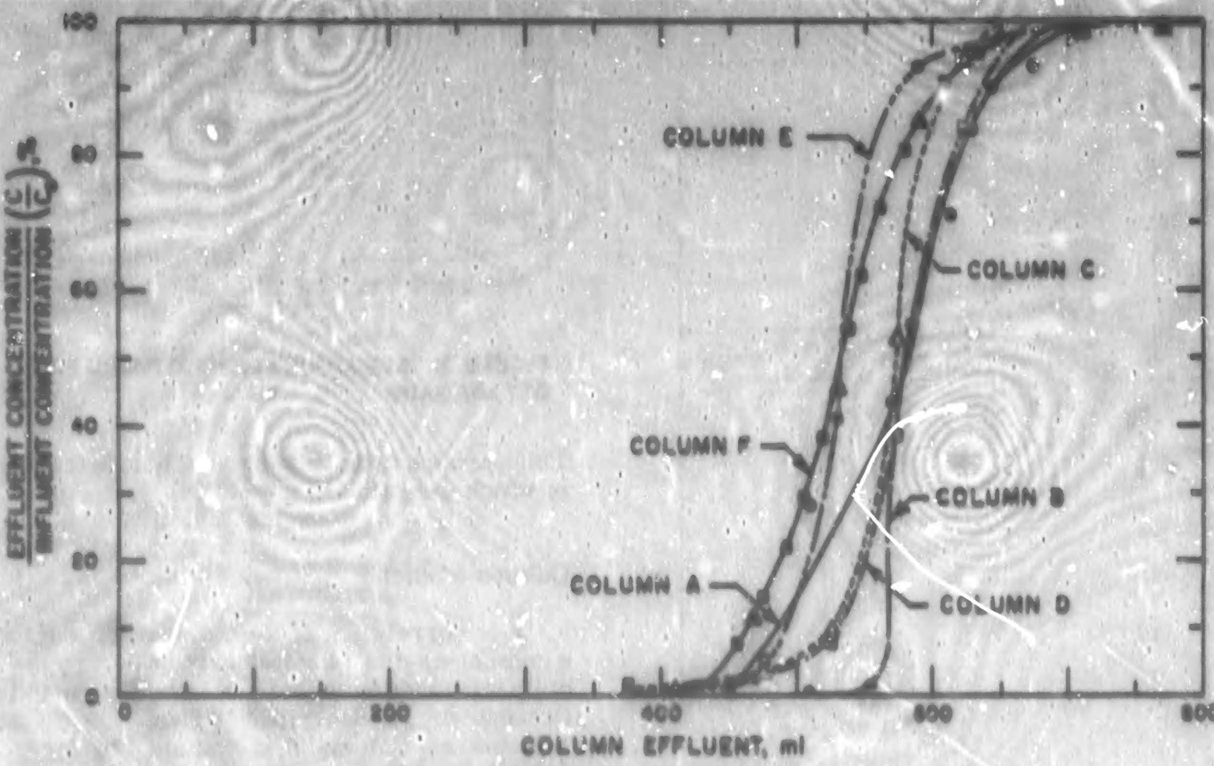

FIGURE 3. CHLORIDE BREAKTHROUGH CURVES FOR COLUMNS A THROUGH F

through curves are presented in Figure 3. The pore volumes, represented by the area to the left of the breakthrough curves, varied from 535 to 595 ml. The porosity of the columns varied from 30.8 to 34.3 percent. The permeability of the columns varied from 534 to 1850 gallons per day per square foot, which is fairly uniform when the high sensitivity of the permeability to the packing of the column is considered. It is concluded that the columns are similar in hydraulic and surface characteristics.

PHYSICAL ADSORPTION

In the first laboratory studies to determine the amount of ABS that would be adsorbed on earth materials, Ottawa sand identical to that used in the biological phase of these investigations was used. This sand was chosen so that information could be gained about the physical adsorption that would undoubtedly accompany any biological uptake.

The physical adsorption was studied both by batch operations in a flask and by continuous flow of ABS solution through columns of sand.

Batch Studies

An experiment was conducted to determine the effect of time on uptake - 25 grams of sand and 50 ml of ABS^{35} solution (10 mg of ABS per l) were placed in each of five flasks. The supernatant was sampled for counting at 5 minutes, 10 minutes, 15 minutes, 1 hour, 2 hours, and 5 hours. The results showed an initial 5-minute adsorption of 3.8 μg of ABS^{35} per gram of sand, and the 5-hour terminal adsorption was 4.2 μg/g. The trend of all the samples was to show the greatest adsorption at 1 hour. The variation of these results are best shown graphically. Figure 4 is a plot of the physical adsorption of the ABS^{35} for the 5 samples. It is concluded that at least 1 hour is required for equilib-

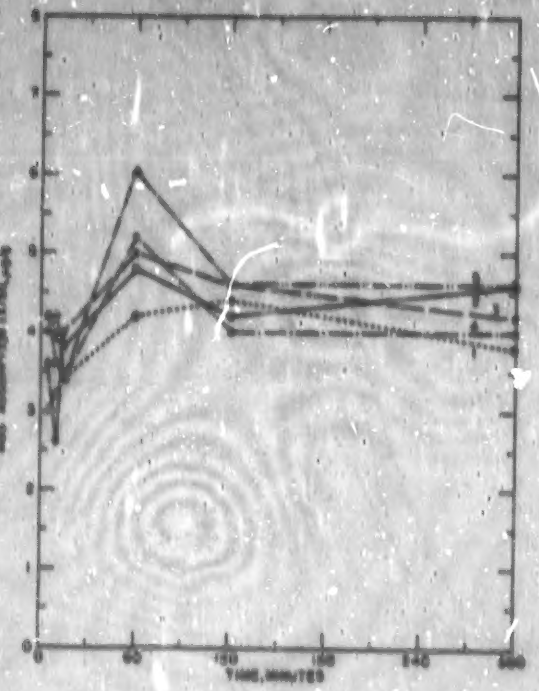

FIGURE 4. ABS ADSORPTION ON OTTAWA SAND

rium to be attained with Ottawa sand. Other finer soils may require much longer.

The next portion of the research was concerned with an isotherm determination to establish the effect of ABS concentration on uptake. Again, 25-gram samples of Ottawa sand were used to measure the ABS^{35} uptake by physical adsorption. Fifty-ml ABS^{35} solutions of various concentrations were added to triplicate sand portions. Constant temperature was maintained in the sand and ABS^{35} solution through the use of a water bath. The supernatants of the mixtures were sampled at the end of 2 hours. The isotherm is shown in Figure 5. Over the range of concentration used in this study, 45 mg/l, the uptake increased almost linearly with concentration. These concentrations cover a wider range than would be expected in ground water. It is to be noted that the uptake at the end of 2 hours for the 8.23 mg/l concentration was 3.5 μg of ABS^{35} per gram of sand. This is 20 percent less uptake than was determined for the above batch study.

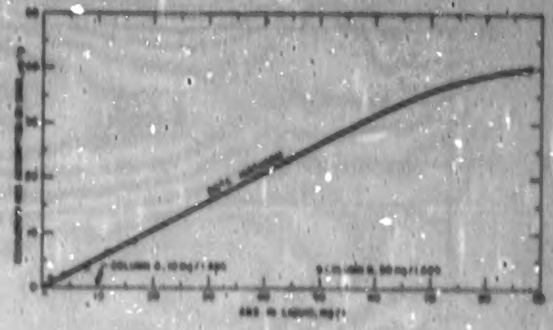

FIGURE 5. ABS ADSORPTION ISOTHERM FOR OTTAWA SAND

This corresponds to a Freundlich isotherm in which the value of n is 1.0.

Column Studies

For correlation of the batch study work, a continuous-flow sand adsorption determination was made by use of a column designated Column B, as described above. The feed solution to Column B contained 10 mg/l ABS^{35}. The flow through the column was approximately 6.5 ml per minute. The Ottawa sand in the column became saturated after approximately 1600 ml of influent had passed through. The saturation curve for this adsorption is shown in Figure 6. The adsorption of the ABS^{35} on the sand amounted to 1.01 μg of ABS^{35} per gram of sand. This was obtained by converting the area between the chloride breakthrough and the ABS breakthrough curve to volume and multiplying by the concentration of the feed solution.

As explained below, Column A was fed with sewage so that a biological slime growth developed on the sand grains and then with ABS^{35} solution so that the physical and biological uptake of ABS could be measured. The solution fed to Column A had an ABS^{35} concentration of 50 mg/l. This higher concentration was used to reach saturation because of the low total amount of flow that could be put through Column A before clogging occurred. To measure the uptake attributable to the biological slime, the physical adsorption on Column A was evaluated by comparison with a strictly physical adsorption on Column B. This experiment differed

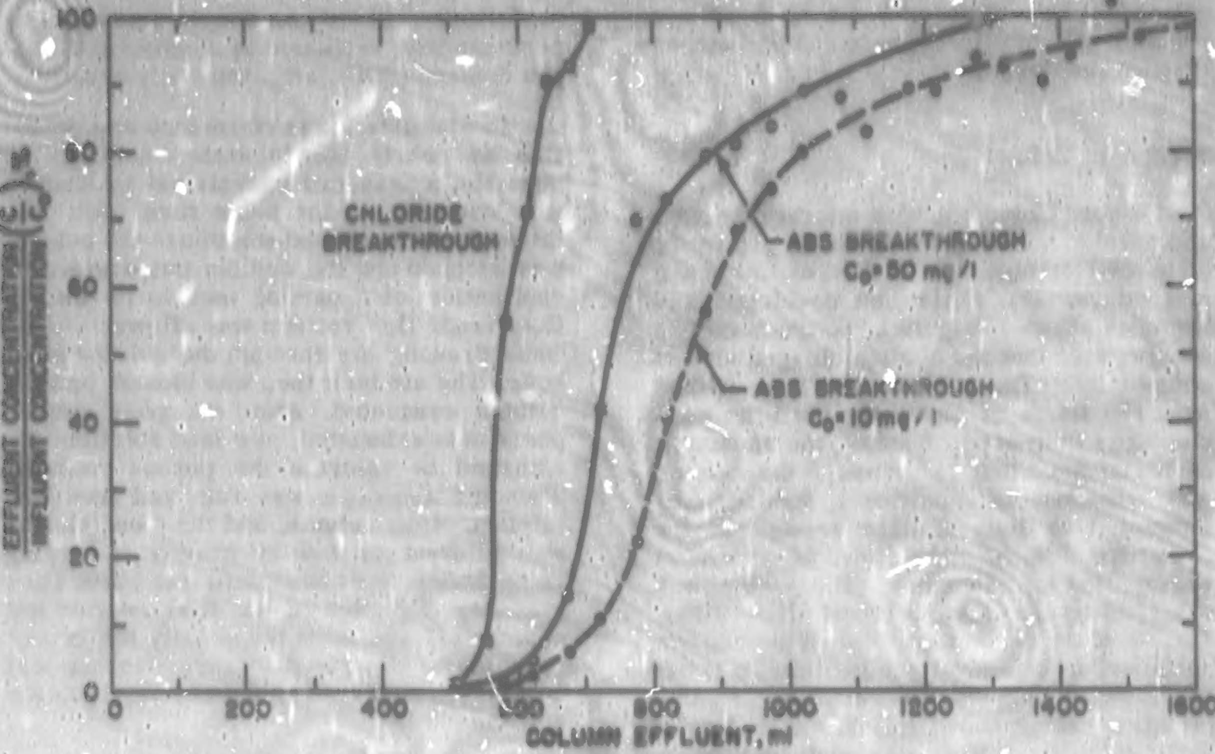

FIGURE 6. BREAKTHROUGH CURVES FOR COLUMN B

from the previous run on Column B in that the concentration of ABS in the feed solution was 50 mg/l instead of 10 mg/l. Before this experiment was made, the dilute (10 mg/l) feed solution was thoroughly flushed from the column. The column became saturated after 1500 ml of the concentrated ABS solution was applied as shown in Figure 6. The uptake for this more concentrated solution amounted to 3.30 μg of ABS^{35} per gram of sand. The average flow through the column during the saturation period was 16.6 ml per minute.

The results of these two continuous-flow column tests are shown on Figure 5 as black circles. It can be seen that under column conditions the sand was not completely saturated with ABS and much less than the equilibrium amount of ABS was adsorbed. This is probably due to the fact that much of the surface of the sand is in contact zones where the space between sand surfaces is so small that there is no movement of water. Saturation of these zones depends upon molecular diffusion to transport the ABS molecules to the sand surface. Molecular diffusion is a very slow process, and in this test, probably did not occur to any great extent.

BIOLOGICAL ASPECTS

Purpose of Experiment

The uptake of ABS on a biological slime was determined by comparison of the ABS removed from solution while passing through a column of Ottawa sand on which a slime growth had developed with the ABS removed while passing through the clean column reported above. It was thought that the comparison of the two columns, one with an active biological slime growth over the sand grains and the other with no growth, would give an indication of the adsorption or degradation phenomenon when the quantity of labeled ABS retained by these two columns was determined. The comparison would be effective, since the two columns were otherwise identical. It was also intended to learn whether the ABS is degraded while passing through the column.

Seeding of Column

To seed Column A with microorganisms and develop a growth on the sand, 115 liters of settled sewage was applied to Column A in 15 days. The slime that developed was black, as shown in Figure 1. So much growth accumulated that the column clogged almost completely. The column was then washed with 175 liters of tap water until the permeability increased. Because the amount of bacterial seed that remained in the column was questionable, additional seeding was attempted; 46 liters of dilute sewage (1 liter of settled sewage and 8 liters of tap water) was applied to the column. The sewage was filtered through glass wool and also settled. The column then was assumed to contain sufficient seed to develop a growth. To avoid increased clogging as a result of further application of suspended solids, the feeding of the column thereafter was continued with a synthetic waste containing only dissolved substrate and minerals. The synthetic waste consisted of 300 mg/l anhydrous dextrose, 50 mg/l ammonium chloride, and 1 ml/l buffer solution containing 8.5 g/l KH_2PO_4, 21.75 g/l K_2HPO_4, 33.4 g/l $Na_2HPO_4 \cdot 7H_2O$, and 1.7 g/l NH_4Cl. All this was made up in tap water to pH 7.2.

Standard Operation

The growth of slime proceeded so rapidly that in a short time the column had clogged so much the flow was practically stopped. The only method found effective in restoring the permeability was to drain the column fluid and then apply a partial vacuum from a water aspirator to the effluent end to draw air through the column. The flow of air over the slime was believed to shrink the slime largely by dehydration. After the permeability was restored, the feeding of the column of synthetic substrate could be continued. No schedule was established initially, but the column was rested and aerated whenever it clogged. Under these conditions the performance of the column, as measured by permeability, reduction in biochemical oxygen demand (BOD), etc., was very erratic.

To stabilize the performance and establish as nearly steady state conditions as possible, a standard operational procedure was adopted. At the same time each day, the application of feed solution to the column was stopped and the column was drained by application of a partial vacuum on the effluent end. This vacuum was allowed to continue drawing air through the column for 1 hour. The air inlet then was closed, and the column evacuated. After the pore atmosphere was exhausted, new feed solution was admitted to saturate the porous medium. Then the aspirator was removed from the effluent of the column, and the feed solution was allowed to flow by gravity at varying rates under fixed head until the same time next day. Samples of the feed solution and column effluent were taken daily for determination of dissolved oxygen, biochemical oxygen demand (BOD), and chemical oxygen demand (COD).

Performance of Column

The BOD of the feed solution for Column A averaged about 200 mg/l, and the BOD load applied varied from 870 to 2710 pounds of BOD per acre per day. The variation was largely due to differences in the amount of feed solution that could be put through the column each day under fixed head conditions. The average BOD loading was about 1200 pounds per acre per day, which is much higher than commonly is applied to sand filters in sewage treatment. Steel (15) reports that the loading on intermittent sand filters should not exceed 150,000 gallons per acre per day. The 200 mg/l BOD would be equivalent to 250 pounds per acre per day.

The removal of BOD by this column varied from 18.4 to 84.6 percent. In view of the very high loading, these figures indicate a high degree of biological activity in the column. The lowest percent removal occurred on the day ABS was applied to the column in a concentration of 50 mg/l. This fact raised the question of the toxicity of the ABS to the biological growth on that day.

The COD removal effected by the column varied from 16.9 to 68.8 percent. These wide variations in percent removal of BOD and COD were not expected and indicate that even with a standardized operating procedure steady state conditions were not attained.

The absence of dissolved oxygen in the column effluent at all times and the appearance of the slime in the column indicated anaerobic conditions. To further evaluate the performance, volatile acids determinations were made on the column. These were found to vary from 58 to 1190 mg/l as acetic acid. The average volatile acids concentration in the effluent of the column was about 100 mg/l, which is not significant in view of the accuracy of the distillation method used in the determination.

ABS Adsorption

After it was established that an active biological slime had developed in the column, the retention of ABS was determined by application of a solution of identical synthetic waste to which had been added 50 mg/l ABS^{35}. Samples of effluent were analyzed by the direct plating technique described above for ABS. The column became completely clogged after 2.3 liters of solution had been used. The breakthrough curve showing arrival of ABS in the column effluent is shown in Figure 7. Unfortunately, the column contents were not completely saturated when the flow ceased, as indicated by the fact that the last effluent sample contained only 50 percent of the ABS in the influent. The ABS that was retained in the column is represented by the area to the left of the ABS breakthrough curve. The ABS retained in the pore fluid is represented by the area to the left of the chloride breakthrough curve multiplied by the average ABS concentration in the pore fluid. The concentration of the pore fluid at the influent end was that of the feed solution, 50 mg/l; that of the pore fluid at the effluent end of the column was 50 percent of that of the feed solution, 25 mg/l. If the average ABS concentration throughout the column is assumed to be 37.5 mg/l, the retention in the pore fluid was 21.3 mg or 7.16 µg per gram of sand. The total retention in the column was computed from the area to the left of the ABS breakthrough curve multiplied by the feed solution concentration. It was found that 89.1 mg of ABS had been retained. The retention on the solid phase, consisting of sand plug slime, was 67.8 mg ABS or 22.80 µg per gram of clean sand. Even though it was not completely saturated, the column that contained slime on the sand retained 7 times as much ABS as the column that contained clean sand. It is concluded that the presence of biological growth significantly increases the ABS retentive capacity of the column.

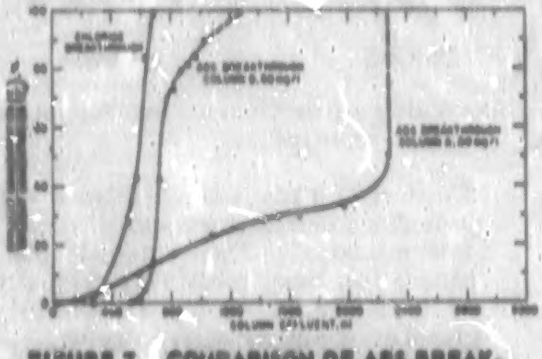

FIGURE 7. COMPARISON OF ABS BREAKTHROUGH CURVES FOR COLUMNS A AND B

In addition to the question of how much ABS was retained in the column, the question was raised as to the possibility that the sulfur-35 counted in the effluent might no longer represent ABS, but rather some degradation product. To determine the fate of the ABS in the column, an effort was made to determine the relative amounts of the sulfur in the column effluent that was still associated with ether-soluble ABS, the amount that was degraded to inorganic sulfur, and the amount that could be classed as intermediate products of degradation. This was accomplished by the ether-extraction, barium-precipitation, filtrate-evaporation procedure described above. The relative activities of sulfur-35 in the three fractions of column effluent taken at the beginning, middle, and end of the run are presented in Table 1.

Table 1. RELATIVE ACTIVITY OF SULFUR-35 IN VARIOUS FRACTIONS OF COLUMN EFFLUENT

Sample number	Average volume throughout, ml	ABS 35[a] cpm/ml	Inorganic sulfur-35,[b] cpm/ml	Total sulfur-35,[c] cpm/ml
11	875	15	0.19	187
32	1475	110	0.05	1009
60	2275	190	0.76	1818

[a] Counted on activated carbon.

[b] Counted on $BaSO_4$ precipitate.

[c] Counted after the original sample was dried in planchet.

It was concluded from these data that the breakdown of ABS into inorganic compounds of sulfur was not evident. Further study is necessary to ascertain the fate of ABS in passing through a biologically active column.

Evaluation of Slime

The amount and nature of the slime growth on the sand in Column A was studied to provide a frame of reference for evaluation of the ABS retention and for comparison with future columns. An indication of the amount and activity of the slime growth was provided by the column performance, as measured by BOD and COD removal and discussed above.

The physical appearance of the slime growth was quite striking. After the initial black slime that developed on the sewage feed was washed out with tap water, the growth of slime on synthetic substrate proceeded. A very characteristic pink color developed on the portions of the column exposed to light. This was thought to be a growth of chromobacteria, light sensitive anaerobes. The rest of the column was covered with a greyish slime except at the top 4 or 5 inches where the growth was black.

To evaluate the slime further, samples were removed from the column at six different depths. The amount of organic matter on the sand was determined by loss on ignition. Unfortunately, the results were not very satisfactory. The number of bacteria in the slime was determined by agitating the sand sample in sterile water. The slime that was thus scrubbed off the sand was decanted with the water, diluted, plated on nutrient agar, incubated at room temperature for 48 hours, and counted. The results are presented in Table 2.

Table 2. CHARACTERIZATION OF SLIME

Sample number	Depth, in.	Volatile solids, mg/g of sand	Total plate count, organisms/g of sand+ slime
1	5.75	1.48	0.96×10^{-11}
2	10.25	88.9	1.00×10^{-11}
3	16.25	0.20	0.88×10^{-11}
4	21.12	12.1	0.84×10^{-11}
5	26.37	---	0.81×10^{-11}
6	34.12	---	0.80×10^{-11}

The total plate count shows remarkably uniform growth of bacteria at all depths. The number of organisms has been expressed in terms of the total solids in the column on a dry weight basis. The total solids included both the slime and the sand.

CONCLUSIONS

The following conclusions are supported by the work reported:

1. The use of radioisotope-labeled ABS provides a satisfactory and convenient determination. The original procedure has been modified principally by transference of the carbon to a planchet by pipette before drying.
2. The physical adsorption of ABS on Ottawa sand is very much lower than on finer earth materials.
3. The adsorption of ABS on Ottawa sand is time dependent. In batch studies,

where intimate contact between sand and water is afforded, at least 1 hour is required to obtain equilibrium. The low adsorption obtained in columns may be in part due to failure to saturate all the surface area of the sand.

4. From the comparison of the retention of ABS on two columns, one with and one without biological growth, it is concluded that the biological growth on earth material enhances the adsorption. With 30 mg/l ABS in the feed solution, 7 times as much ABS was retained on the solid phase of a column in which a biological slime had been developed.

5. It has not been fully determined to what extent the retention was due to adsorption of the large surface area afforded by these bacterial cells, but it appears that this is an important phenomenon.

6. It is concluded that the adsorption on biological slime is one mechanism that retards the movement of ABS in a septic tank drain field.

ACKNOWLEDGEMENT

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REFERENCES

1. Flynn, J.M., Andreoli, A., and Guerrera, A.A., Study of Synthetic Detergents in Ground Water, Jr. AWWA, 50, 1551 (Dec. 1958).
2. Walton, Graham, ABS Contamination, Jr. AWWA, 52, 1354 (Nov. 1960).
3. Deluty, Jerome, Synthetic Detergents in Well Water, Public Health Reports, 75, 75 (Jan. 1960).
4. Weaver, P. J., Review of Detergent Research Program, Jour. Water Pollution Control Fed., 32, 288 (Mar. 1960).
5. AASGP Committee, ABS and the Safety of Water Supplies, Jr. AWWA, 52, 786 (June 1960).
6. Public Health Service Drinking Water Standards, 1946, Public Health Reports, 61, 371 (1946).
7. Hopkins, O. C. and Gullans, O., New USPHS Standards, Jr. AWWA, 52, 1161 (Sept. 1960).
8. Lauman, C. W., Co., Effect of Synthetic Detergents on the Ground Waters of Long Island, N. Y., New York State Water Pollution Control Board Research Report No. 6 (1960).
9. Renn, C. E. and Barada, M. F., Adsorption of ABS on Particulate Materials in Water, Sewage and Industrial Wastes, 31, 850 (July 1959).
10. McGauhey, P. H. and Klein, S. A., Removal of ABS by Sewage Treatment, Sewage and Ind. Wastes, 31, 877 (Aug. 1959).
11. Sawyer, C.N., Effect of Synthetic Detergents on Sewage Treatment Processes, Sewage and Ind. Wastes, 30, 757 (June 1958).
12. McKinney, R. E. and Symons, J. E., Bacterial Degradation of ABS. I. Fundamental Biochemistry, Sewage and Industrial Wastes, 31, 549 (May 1959).
13. APHA, Standard Methods for Examination of Water Sewage and Industrial Wastes, 11th Ed. (1960).
14. Final Report on the Fate of Alkylbenzenesulfonate in Sewage Treatment, Sanitary Engineering Research Laboratory, University of California, Berkeley (July 1957).
15. Steel, E. W., Water Supply and Sewerage, Fourth Edition, page 519, McGraw-Hill Book Co., New York (1960).

U.S. GEOLOGICAL SURVEY RESEARCH STUDIES

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The detrimental effects of man-made wastes on water resources are increasing at a rapid rate. Water in all states of natural occurrence--on the land, in the air, and in the oceans--is subject to contamination. Researchers on how water is contaminated and what happens to the contaminated water in the hydrologic cycle must consider water in all of its aspects. Because ground water is a transitory phase of the hydrologic cycle, studies directed to the contamination of ground water cannot overlook both antecedent influences and future uses of the water.

The Geological Survey is engaged in many categories or phases of fundamental and applied research on water problems. One category deals with research on river hydraulics, stream-channel development and morphology, and sediment transport. A second category includes research in limnology, evapotranspiration, evaporation suppression, and heat energy budgets. A third category includes quantitative studies of the flow of water in the saturated and unsaturated zones of the ground, the mechanics of ground water reservoirs, and properties of porous media. A fourth category includes research on the geochemistry of water, the physical and chemical interrelations of precipitation, surface flows, and ground water, and the effects of man-made environmental changes on water and water supplies. Our attention today is directed to this last area of study with special reference to ground water contamination.

As early as 1906, the Geological Survey published reports on the prevention of ground water contamination through careful construction and maintenance of wells(1). A few years later, reports were published on pollution of underground waters in limestone and on the protection of shallow wells in sandy soils(2). In a study of limestone aquifers, tests were made on the connection between sink holes and springs by the introduction of common salt into limestone sinks and measurement of the amount of chloride at the spring outlet. These tests indicated that water flowing through limestone channels receives no filtration and very little purification. Recommendations were made that the practice of dumping garbage and filth into sink holes be abandoned. Early investigation of shallow wells in sandy soils showed that the distance pollution is carried depends on the amount of rainfall, the number of sources of contamination, the amount of pollution entering the aquifer, the porosity and grain size of the formation, the slope of the surface and elevation of the outlet, and the temperature of the water.

Today we face many ground water problems that were unknown 50 years ago. Synthetic detergents and radioactive wastes are two examples. In 1959, over 525 million pounds of the sulfonated dodecylbenzene type of synthetic detergents were produced in the United States. This figure represents a 75 percent increase over the 1954 production. Because this type of detergent is not easily decomposed, it persists even after passing through sewage treatment plants and is finding its way not only into surface waters but also, to an increasing extent, into ground waters.

Radioactive wastes threaten to become an increasing hazard. Although permissible limits for discharge of radioactive wastes are very low, the sheer number of useful applications of radioactive materials automatically increases the potential for harmful contamination of all sources of water supply.

According to estimates now current, there may be about 700 reactors in operation by 1980. Eliassen(3) estimated that by 1980 we may be producing fission products having a total radioactivity of 100 billion (100×10^9) curies per year. The estimated accumulated volume of stored waste may be 200 million (200×10^6) gallons by 1980, 600 million by 1990, and 2,400 million by 2000. In 1965, waste fission products may be produced at a rate of about 10 kg per day(4).

RESEARCH ACTIVITIES OF USGS

Many of the research investigations by the Geological Survey bear directly or indirectly on problems of contamination of ground water. Some examples of current research activities are given in the paragraphs that follow.

Organic Substances in Water

Although considerable research has been done by other agencies on organic wastes in water, not much is known about the sources and the chemical composition of naturally occurring organic materials in surface and ground waters. The Survey is working on the development of suitable methods for the separation, identification, and measurement of these naturally occurring organics. Such methodology, if successful, should also be applicable to organic wastes found in water.

The development of methodology is a formidable task. Techniques of sampling, extraction, concentration, handling of minute samples, and the application of such tools as chromatography and infrared spectroscopy all present special problems.

Behavior of Detergents and Other Pollutants in Soil-Water Environments

The Geological Survey, in cooperation with the Federal Housing Administration, recently began studies to determine the fate of waste materials during the course of travel of water underground. The initial emphasis is on synthetic detergents because they are showing up in ground water used for human consumption. Significant factors are the horizontal and vertical rates of percolation of detergents through the ground. Do they move at the same velocity as the water? Are detergents present in large enough concentrations to alter significantly the surface tension and viscosity of ground water? To what extent are detergents sorbed on soil materials? After sorption, under what conditions are they released? Do certain types of soil materials catalyze the decomposition of synthetic detergents? Is the rate of movement of pathogenic organisms in ground water increased or decreased by the presence of detergents?

Laboratory experiments that we hope will provide answers to these and related questions are being set up.

Radioactive Wastes

The activities of the Geological Survey in problems of radioactive waste disposal have been summarized by Nace (5, 6).

The Survey is studying several problems involving radionuclides. A prerequisite to research on radioactive wastes in water is a knowledge of natural levels of radioactivity. These natural levels for radium and uranium have been established in terms of median concentrations for the geotectonic regions of the United States. Some areas have been partially delineated both geographically and geologically where beneficially used water contains more radium than the maximum permissible concentration for human consumption. Although median values for radium for geotectonic regions generally are less than 0.5 micromicrocuries per liter, individual concentrations ranging up to 22 micromicrocuries per liter have been observed.

Concentrations of naturally occurring strontium-89 have been determined on samples from more than 80 sites on major rivers of the United States. Concentrations range from 0.01 to 9.5 ppm. Analyses of selected ground water sources show concentrations as high as 50 ppm in a few areas. Although the significance is not yet clear, the distribution and concentration of strontium-89 may be important in relation to radioactive strontium-90 resulting from fallout from the atmosphere.

Studies are in progress to determine the mode and rate of mixing of radioactive wastes discharged to natural water courses. Observations are being made to learn how fast these waste materials travel downstream and how they react on contact with stream sediments. We need to know under what conditions the radioactive substances are sorbed on sediments, especially on the clay fractions, and also under what conditions they may be re-released to the streams. We also want to know how radioactive substances are extracted by aquatic organisms and how they are subsequently released to the environment. Some of our limnological research will be pointed in this direction.

Ground water research bearing on the radioactive waste disposal problems includes studies of (1) the vertical movement of water through unsaturated earth above the water table and in the zone of saturation and (2) the heat potential of waste material injected or stored at depth underground.

Research is being conducted on the sorption of certain radionuclides on clays and other minerals. An improved method has been developed for determining cation-exchange capacity of clay minerals by the use of radiocesium. It has been found that cesium sorbed on illite becomes irreversibly "fixed" upon drying of the clay.

Movement of Liquids in Clays

Laboratory facilities are being set up to study liquid-movement phenomena in clay and clayey soils. Movement in these materials is highly complex and defies analysis in terms of conventional factors such as hydraulic gradients, porosity, and liquid viscosity. The phenomena of liquid movement in clays are related to the less clearly understood factors such as induced and applied gradients of electrical potential, ionic concentration, temperature, and mineralogical and chemical compositions of the clay and pore liquid. Initially, we plan to study separately the effects of these factors on the rates of liquid movement and then to analyze the manner in which they are interrelated.

Spatial Distribution of Chemical Constituents in Ground Water

This research seeks to identify the relationships between hydrologic and mineralogic factors and the chemical character of the ground water. The project area is the Atlantic Costal Plant where the geology provides a diverse framework suitable for a regional approach to the study. Clay samples and their associated waters are being analyzed to determine what effects clays have on the chemical character of the water. Thermodynamic principles will be applied in developing reactions and in calculating equilibrium constants to determine if water and clays are in equilibrium. Also in progress is the comparison of equilibrium conditions between ground water and calcium carbonate in limestone. We want to relate to natural field environments the theoretical equations or "models" that describe the limits of pressure, temperature, pH, and oxidation potentials, under which particular species of ions exist.

Laboratory model studies in which artificial sandstone is used as an aquifer are in progress. These studies show the magnitude and effects of cyclic types of flow. These flows simulate the effects produced by dispersion in a costal aquifer. Mathematical analysis is made of the flow of fluids of variable density in the zone of diffusion. Boundary conditions are selected to approximate actual flow systems observed in the field.

Other Research

Other research investigations by the Survey that relate to the contamination of ground water are (1) chemistry of hydrosolic metals, (2) geochemistry of minor elements, (3) mineralogy of fluvial sediments, and (4) isotopic hydrology.

ULTIMATE GOALS

The Geological Survey shares the concern of other scientific agencies on deficiencies in knowledge about ground water contamination. Our ultimate goal is a better understanding of:

1. The controls on water quality under conditions of natural environment.

2. Chemical and physical changes in quality resulting from the introduction of man-made wastes.

3. The fate of cultural waste when released to water and its environment.

To accomplish these goals, we must enlist talents represented by many disciplines, including organic and analytical chemistry, geochemistry, and radiochemistry; geology and geohydrology; engineering, physics, and mathematics; and limnology, biology, and bacteriology. Nearly all of these disciplines are represented on the Geological Survey staff of research scientists. We feel both a responsibility and an opportunity to advance knowledge on a broad front that should contribute significantly toward a better understanding of the complex problems resulting from contamination of water in its total environment. We are aware that we must increase our efforts to provide answers to these problems that must be resolved in order to provide the quantity and quality of water needed for a rapidly expanding economy.

REFERENCES

1. Fuller, M. L. Underground-water papers, 1906. U. S. Geol. Survey Water-Supply Paper 160, 1906.

2. Fuller, M. L. Underground-water papers, 1910. U. S. Geol. Survey Water-Supply Paper 258, 1910.

3. Eliassen, Rolf. Outlook for waste disposal. Nucleonics, v. 15, no. 11, 157-158, 1957.

4. National Academy of Sciences - National Research Council. The biological effects of atomic radiation. Summary reports, Report of the Committee on Disposal and Dispersal of Atomic Wastes, 101-108, 1956.

5. Nace, R. L. Activities of the United States Geological Survey in problems of radioactive-waste disposal. Hearings before the Special Subcommittee on Atomic Energy, Congress of the United States, Eighty-Sixth Congress, First Session, on Industrial Radioactive waste Disposal, Jan. 28-Feb. 3, 1959, v. 4, p. 2580-2645.

6. Nace, R. L. Contributions of geology to the problem of radioactive waste disposal. Conference on Disposal of Radioactive Wastes, sponsored by International Atomic Energy Agency, Vienna, 1960.

GROUND WATER CONTAMINATION RESEARCH AND RESEARCH NEEDS

P. H. McGauhey, University of California

During the past 2 day's discussion of hydrogeological aspects, types, specific instances, and regulation of ground water contamination, the nature of what has been revealed through research and what yet needs to be explored has become almost self-evident. Essentially all that can now be added is a resume of that fraction of the needed research that is already in progress, and a summary of the needs noted or implied during the previous sessions of this Symposium. A brief recounting of the more important recent research might also be useful in case the results may have been distributed inadequately, and thus a great deal of "fragrance" wasted "on the desert air."

From its inception in 1950 the Sanitary Engineering Research Laboratory of the University of California at Berkeley (SERL) has been concerned with ground water quality. Two types of projects pertinent to this subject have been, or are now being, conducted: (1) those that deal directly with underground water, and (2) those concerned with changing the quality of water before it is allowed to enter the soil or the ground water itself.

PREVIOUS RESEARCH

Major projects that have been completed in the last 7 or 8 years include the following studies.

A 4-year field study of the underground travel of pollution during ground water recharge by direct injection of sewage effluents (1). In this study, bacteria were found to travel less than 100 feet in a fairly coarse aquifer, as contrasted with the free movement of most dissolved solids.

A 28-month field study of water reclamation by surface spreading at Lodi, California (2). The investigators found no bacterial penetration below 2 feet, a quick adsorption of ammonia on soil particles, and ready movement of most dissolved solids to the 13-foot maximum depth of observation.

An intensive study of the Lodi results on five California agricultural soils in pilot-scale lysimeters (3). This study related pollution travel to soil characteristics and established an empirical method for predicting the behavior of a soil under sewage spreading.

A detailed study of the depth of penetration, as a function of soil characteristics, of organic matter and bacteria into soils spread with sewage effluents (4). Results showed clogging to be a surface phenomenon with little penetration of organisms.

A model study of the phenomenon of sea intrusion into over-developed fresh water aquifers in coastal areas and of the behavior of a fresh water mound injected as a barrier to intrusion (5, 6). A lapse-time color motion picture of the behavior of intruding sea water and injected fresh water was produced and is still in demand by technical groups.

RECENT AND CURRENT RESEARCH

More recent research projects that are currently in progress, although the results of various experiments may have already been released in reports to sponsoring agencies, include the following.

Detergent Studies

A series of studies on the behavior and fate of alky benzene sulfonate (ABS) have been undertaken by the SERL under sponsorship of the Association of American Soap and Glycerin Producers, the Public Health Service, and the University of California. One of these (7), completed in 1957, shows that normal activated sludge treatment may be expected to remove from 50 to 70 per cent of the normal concentration (5-10 mg/l) of ABS presently in domestic sewage. In the second study (8), a technique of surface stripping of induced froth was developed by which ABS may be reduced to 1 mg/l before a sewage effluent is released to receiving waters or introduced underground.

A third study, now in its early months, is directed to methods of further reducing ABS, should detergent removal become an objective of sewage treatment, and to the behavior of ABS underground in a variety of environmental conditions. This study is soon to be expanded to include a determination of the potential of foam fractionation to upgrade the quality of waste waters.

Percolation Studies

Under the sponsorship of the Federal Housing Administration, studies of the phenomenon of clogging of septic tank percolation fields have been in progress for more than 2 years. Both the phenomenon involved in introducing sewage effluent underground and the nature of the percolate are under investigation. In a completed phase of the study (9) it was found that ferrous sulfide formed under anaerobic conditions is an important factor in soil clogging and is responsible for the black color previously widely assumed to be organic matter accumulated in the soil. Other factors, too involved to introduce on this occasion, led to a second study, now in progress, intended to explore means of improving both the rates of infiltration and percolation of sewage effluents in a soil and the quality of the percolate reaching the ground water.

Ground Water Tracing

A variety of studies concerned with methods of tracing and studying the movement of ground water have been initiated by SERL and Hydraulic Engineering Laboratory staff members at the University of California under sponsorship of such agencies as the Atomic Energy Commission, the Bureau of Reclamation, and the University's own Water Resources Center. These groups are developing not only a much needed hydrological tool but also a means for predicting the safety of ground disposal of refuse, industrial wastes, radioactive wastes, etc. in any particular circumstance and a means for tracing the source of observed ground water contamination.

A field installation of 23 wells previously constructed (1) for the investigation of pollution travel during direct injection of sewage effluents into a confined aquifer is being used in comparison studies of the characteristic breakthrough curves for various chemical tracers such as chlorides, fluorescent dyes, sugar, etc. The applicability of helium to ground water tracing in a confined aquifer also was determined (10) by controlled experiments.

Development of techniques and their application in the use of tritium as a water tracer began in 1957 and is being continued in laboratory and field-scale experiments. First, work was directed to methods of measuring low concentrations of tritium with the ease, economy, and reproducibility requisite for practical ground water tracing. A statistical sensitivity criterion for tritium measurements was established. With this as a basis, procedures were developed for measuring in a matter of some 30 minutes tritium in a liquid scintillation apparatus in concentrations as low as 3×10^{-6} uc/ml. Current studies in low-level tritium measurement are concerned with methods of reducing background, which at present appears to result from internal contamination and hard gamma radiation of cosmic origin.

Application of the tritium measurements to a study of the loss of water from unlined irrigation canals and its effect on local ground water quality was begun in 1959 and is still in progress. On November 3, 1959 (11), ten 1-curie sources of irradiated water were added to an 800-foot ponded reach of the Madera Canal, located on the east side of the San Joaquin Valley in California. Sampling wells along the canal were soon found to contain tritium. In January 1961, samples of the ground water near the canal continued to show the presence of tritium, although the peak of the tritium wave had progressed over 350 feet from the center line of the canal. Concentrations at that distance were 9.4×10^{-5} uc/ml, or about 6.5 percent of the initial concentration in the canal. Characteristics of the tracer wave, as determined by ground water samples drawn from wells perforated over their entire 10- to 16-foot depths, showed enormous longitudinal dispersion or mixing in the pertinent geologic formation. Although ground water in the region has an average velocity of 20 to 40 feet per day, measurable concentrations of the tritium tracer are expected to persist for many years.

These results suggest a need for research into the long-term effects of pollutants before water containing some of the newer micropollutants is introduced underground either purposefully or during the ordinary use of the pollutants.

A study of methods of determining the velocity and direction of ground water flow from observations at a single well is in progress. An apparatus has been developed that permits isolation of a section of a cased deep well, provides for circulating the contents of the section together with the inflow of ground water through the casing, and allows continuous monitoring of the well contents. Study of the decay characteristics of a tracer as a result of dilution permits estimates of fluctuation and of the coefficient of eddy diffusion in homogenous turbulence, leading to the establishment of relationships that may yield estimates of flow velocity and duration.

Results of a model study of seepage from leveed rivers into low-lying agricultural land have recently been reported (12, 13). From well logs and other data, pertinent to the lower Sacramento Valley and the Sacramento-San Joaquin Delta, geologic cross sections perpendicular to channels were plotted. An electric analog was then designed to yield quantitative seepage data. In the analog layered soils of differing permeabilities are represented by electrolytes of differing conductivities. Directional permeability characteristics of soils are included by transforming model scales. Sloping water tables are represented by variable potentials obtained from a battery of electrical resistances that furnish potential differences as small as 2.5 percent. Flow on equipotential lines is traced by a pantograph for given voltage drops by visual inspection of an oscilloscope. More than 60 representative geologic sections have been analyzed with this device. The results demonstrate a practical method that can be used to predict the seepage of imported surface waters into local ground waters and hence of their effects on ground water quality. In combination with other techniques and considerations the method offers possibilities for study of the contamination of adjacent ground waters by surface flows dedicated to the transport of urban-industrial or agricultural waste waters.

Experimental work on the dynamics of fresh-salt water movement on either side of an interface has included analytical and experimental studies of the mixing of fresh field conditions and is now being reported (14, 15, 16, 17, 18, 19). In a current investigation a parallel plate model is used to study the distribution of these two types of water in irrigated areas subject to upward seepage of saline waters.

For the past 10 years studies of the disposal of radioactive wastes have been in progress in the SERL under the sponsorship of the Atomic Energy Commission, the Office of Civilian Defense Mobilization, and the Public Health Service. Some of these deal with the ground disposal of such wastes, whereas others concern the problem of radioactivity in contaminated surface waters that may be used directly or ultimately become mingled with the ground water through natural or artificial recharge.

Studies (20, 21) of various systems for the injection of radioactive wastes into deep connate water-bearing formations are in progress in both the laboratory and field. Both tracer tests and laboratory ion-exchange studies have been conducted, the objective being a knowledge of the degree to which various isotopes may be tied up by various underground formations as a basis for the design of underground disposal systems of predictable capacity. On a field scale an inverted 5-spot pattern of wells penetrating a 5-foot confined aquifer 100 feet below the ground surface has been installed at the Richmond Field Station of the University. With it a simulated waste water will be injected at a central well and treated water removed from four corner wells. Explorations with tritium were started in March 1961.

Studies pertinent to the problem of disposal of wastes from increasing scientific, medical, and industrial use of radioisotopes are in progress. A current project seeks to identify the parameters and to formulate the relationships that describe the leakage of radionuclides through ion-exchange columns intended to decontaminate wastes. The project also includes work on the development of a rational basis for the design of such ion-exchange systems.

A current study sponsored by the Office

tamination of drinking water by ion exchange is centered on radioyttrium, which because of its tendency to form colloids presents special problems. Column experiments involving four different waters are in progress. Two of the waters are natural, and two are synthetic. The only cations present in the latter are either sodium or calcium, to facilitate correlation of the results with theory.

SUMMARY

Despite the present impressive volume of research, the need for research has been growing faster than results are being produced. A summary of specific research needs is the subject of another author so I shall note only some areas of need. One of these areas is the nature, significance, and underground behavior of a growing list of organic and inorganic microcontaminants. In this connection I may cite an analogy with air pollution where, after a long history of study of the macroconstituents of the atmosphere, the microcontaminants, about which we know next to nothing, suddenly brought us to both tears and disaster. In water contamination again we have standard methods of macroanalysis, but none at all for the coming microproblems. The second major area includes this whole matter of both the short-term and long-term effects of liquid and solid waste disposal practices, and indeed the matter of all beneficial uses of a fixed supply of water by an exploding urban-industrial population on the quality of our waters. Both the mechanisms by which contamination comes about and methods of control are in need of investigative work.

ACKNOWLEDGEMENTS

Appreciation is hereby expressed to my fellow members of the staffs of the Sanitary Hydraulic Engineering Laboratory of the University of California, especially to Professors Warren J. Kaufman, David K. Todd, and Gerald T. Orlob, on whose writings I have drawn freely in describing the experimental work in progress. I have abridged these writings in the interest of brevity, clarity. Omission of any reference to the work of other researchers in the field of ground water contamination with which I am familiar results from my interpretation of the time limits and the scope of my assignment on the program.

REFERENCES

1. Gotaas, H. B. et al. Investigation of Travel of Pollution. Publication 11. Calif. State Water Pollution Control Board, Sacramento. 1954.

2. Greenberg, A. E., McGauhey, P. H., and Gotaas, H. B. Field Investigation of Waste Water Reclamation in Relation to Ground Water Pollution. Publication 6. Calif. State Water Pollution Control Board, Sacramento. 1953.

3. Greenberg, A.E. and McGauhey, P. H. An Investigation of Sewage Spreading on Five California Soils. Tech. Bull. 12, I. E. R. Series 37, Issue 12. San. Engr. Res. Lab., Univ. of Calif., Berkeley. 1955.

4. Orlob, G. T. and Krone, R. B. Movement of Coliform Bacteria Through Porous Media. Final Report. San. Engr. Res. Lab., Univ. of Calif., Berkeley. 1956.

5. Todd, D. K., McGauhey, P. H., and Simpson, T. R. An Abstract of Literature Pertaining to Sea Water Intrusion and Its Control. Tech. Bull. 10, I.E.R. Series 37, Issue 10. San. Engr. Res. Lab., Univ. of Calif., Berkeley. 1953.

6. Harder, J. A. et al. Report on Laboratory and Model Studies of Sea Water Intrusion. Tech. Bull. 11, I.E.R. Series 37, Issue 11. San. Engr. Res. Lab., Univ. of Calif., Berkeley. 1955.

7. McGauhey, P. H., Crosby, E. S., and Klein, S. A. The Fate of Alkylbenzenesulfonate in Sewage Treatment. Final Report. San. Engr. Res. Lab.,

8. McGauhey, P. H. and Klein, S. A. A Study of Operating Variables as They Affect ABS Removal by Sewage Treatment Plants, Final Report. San. Engr. Res. Lab., Univ. of Calif., Berkeley. 1960.

9. Winneberger, J. H., Francis, L., Klein, S. A., and McGauhey, P. H. Biological Aspects of Failure of Septic-Tank Percolation Systems. Final Report. San. Engr. Res. Lab., Univ. of Calif., Berkeley. 1960.

10. Carter, R. [illegible] Todd, D. K., Orlob, G.T., and Kaufman, W. J. Measurement of Helium in Ground Water Tracing. Water Resources Center Contribution 21. San. Engr. Res. Lab., Univ. of Calif., Berkeley. 1959.

11. Sanitary Engineering Research Laboratory, Univ. of Calif., Berkeley. News Quarterly, 11(1):5. January, 1961.

12. Todd, D. K. and Bear, J. River Seepage Investigation. Water Resources Center Contribution 20. Hydraulic Engr. Lab., Univ. of Calif., Berkeley. 1959.

13. de Jong, G. de J., Todd, D. K., and Hagen, D. W. Permeability Tests of a Delta Peat. Water Resources Center Contribution 31. Hydraulic Engr. Lab., Univ. of Calif., Berkeley. In preparation.

14. de Jon, G. de J. Vortex Theory for Multiple Phase Flow Through Porous Media. Water Resources Center Contribution 23. Hydraulic Engr. Lab., Univ. of Calif., Berkeley. 1959.

15. de Jong, G. de J. Singularity distributions for the analysis of multiple-fluid flow through porous media. J. Geophys. Research. 65:3739-3758. 1960.

16. Bear, J. and Todd, D. K. The Transition Zone between Fresh and Salt Waters in Coastal Aquifers. Water Resources Center Contribution 29. Hydraulic Engr. Lab., Univ. of Calif., Berkeley. 1960.

17. Bear, J. On the tensor form of dispersion in porous media. J. Geophys. Research. In press.

18. Bear J. and Todd. D. K. Transition zone of the interface in coastal aquifers. Proc. Hydraulics Div., Amer. Soc. Civil Engrs. In preparation.

19. Bear J. Some experiments in dispersion J. Geophys. Research. In preparation.

20. Kaufman, W. J., Ewing, B. B., Kerrigan, J. V., and Inoue, Y. Disposal of radioactive wastes into deep geologic formation. J. Water Poll. Control Fed. 33(1):73-84. January, 1961.

21. Ray, A. D., and Kaufman, W. J. An Investigation of Ion Exchange Treatment of Strontium-90 Contaminated Organic Wastes. Preliminary Report. San. Engr. Res. Lab., Univ. of Calif., Berkeley. 1961.

SEWAGE RECLAMATION BY PRESSURIZED RECHARGE OF AQUIFERS

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Sewage reclamation by pressurized recharge of aquifers is a research project in its initial stages at the California Institute of Technology under the direction of the junior author and Dr. G. J. Mohanrao. The research is being financed in part by a grant (RG-8084) from the National Institutes of Health. Inasmuch as no data are yet available, this paper will be limited to a description of what we hope to accomplish and how

BACKGROUND

In arid areas, and especially in southern California, the need for reclamation and reutilization of nonsaline waste waters is apparent and urgent. Reutilization may be direct, especially for agriculture and certain industries, or it may be indirect, i. e. after recharge to ground water basins where the waste water loses its identity and blends with natural waters. Most ground water, however, occurs in deep confined aquifers where it is not susceptible of recharge from spreading basins at the surface. For such recharging, it is possible to employ deep wells perforated at the proper aquifers and subjected to pressures.

The oil industry has had considerable experience in the flooding and pressurizing of oil-bearing sands with waste brines, but not much of the information so developed is applicable to the problems encountered in sewage reclamation. In many instances, however, brines have had to be treated chemically and filtered through sand or diatomite before they could be recharged.

With sewage, there are two major problems: (1) What degree of treatment is necessary before sewage can be recharged without clogging the interstices of sand near the well and what parameters are best able to describe rechargeability, and (2) what is the effect of travel through soil on the chemical and biological contaminants in the treated sewage.

The Los Angeles County Flood Control District (LACFCD) presently is engaged in a project to stop salt water intrusion of fresh water aquifers by a line of recharge wells. Filtered and softened municipal water now is being used for this purpose, but the wells are near the Hyperion sewage treatment plant and possibly might be able to use a high-grade effluent from that plant. The LACFCD has conducted a few field tests to determine the suitability of sewage for recharging, but the results were inconclusive owing to limited time and budgets and the lack of proper controls and scientific testing. The District is planning now to renew field testing under the guidance of Caltech engineers, with concurrent laboratory experiments under controlled conditions in the W. M. Keck Engineering Laboratories at C. I. T.

PROCEDURES

The field experiments, conducted and supported financially by LACFCD, involve the construction of a demonstration-type rapid sand filter with automatic backwash facilities to polish the highly oxidized effluent of the conventional activated-sludge process at the renovated Hyperion plant. This polished effluent will be recharged through a 24-inch well, and the ground water will be sampled at several observation wells at varying distances. Samples also will be taken of the Hyperion effluent before and after sand filtration.

Samples will be taken routinely from the final effluent of the Hyperion activated-sludge plant, the same water after filtration through sand under controlled operating conditions and different chemical treatments and the water that is sampled from observation wells at varying distances from the injection well. Analyses of these samples will include BOD, suspended solids, total solids, pH, turbidity, color, chlorides, hardness, alkalinity, total bacteria, coliform organisms, nitrogen components, syndets (ABS), and the MF "clogging ratio." In addition, occasional tests will be run for heavy metals, phenol, boron, fluoride, and other constituents of possible interest. Personnel of the LACFCD will measure hydraulic parameters such as discharge, head losses in filtration, backwashing characteristics, injection heads, and the slope of the phreatic line between observation wells.

It is recognized that the field tests provide little opportunity for controlled experimentation. For this reason, Caltech personnel are constructing laboratory models to simulate the flow of treated waste waters through various types of porous media under controlled conditions. The procedure will involve passing an artificial sewage plant effluent through soil columns and determining the effects of such percolation on the physical, chemical and biological qualities of the sewage.

The types of soils to be used in this study will be limited to those that may be expected in areas where recharge of waste water into the ground is contemplated or proposed. Soils similar to those found near the City of Los Angeles' Hyperion activated-sludge plant definitely will be used. Variables such as permeability, exchange capacity, and structure appear to be significant in the proposed research.

The soil columns will be enclosed in sections of 8-inch asbestos-cement pipe with a basic length of 2 feet. The short length will simplify the packing process and result in a more uniform permeability. The short segments are easily connected into any desired length by use of the normal asbestos-cement connectors and rubber rings. Multiplicity in length will allow detention times to be varied.

One further advantage of small segments is that they may be easily sterilized so that tests free from any biological effects may be conducted to determine the ion-exchange properties of the soil, to investigate physical removal by filtration, and to determine any solubility effects.

Material for the casings of the columns presents a problem because of the wide variety of conditions it must withstand. Asbestos cement is believed to give the desired inertness and is much more economical than other available materials that would withstand the rigors of the tests.

Waste water will be artificially prepared to duplicate as closely as possible a filtered effluent from a secondary-type sewage treatment plant. The use of artificial effluent will allow reproducibility of test conditions and control of single variables. Large portions of this artificial waste water or "stock" may be sterilized and stored for extended periods, thus eliminating the necessity for continually obtaining actual plant effluent. The use of a "stock" also permits the addition of any desired biological flora to the soil column.

The variability of biological flora will permit the addition of specific organisms in order that particular substances may be degraded. One aim of the proposed research is to determine whether accelerated removals of certain biologically decomposable constituents can be obtained by increasing the populations of certain species of organisms.

Flow through the column will be sampled through ports located in each 2-foot section of the pipe. Samples of influent and final effluent also will be taken. Routine analyses will be conducted for suspended solids, turbidity, color, chlorides, hardness, pH, and alkalinity. Special considerations will be given to the $CaCO_3$ saturation index, biochemical oxygen demand, chemical oxygen demand, the components of the nitrogen cycle, detergents, dissolved oxygen, biological flora, phenol, boron, and heavy metals. Hydraulic losses through the column also will be recorded.

Proposed test variables, some of which have been mentioned previously, are as follows:

1. Soil column variability, both in chemical and physical constitution and also in permeability.
2. Rate of waste water flow through soil.
3. Detention times of waste in column.
4. Biological flora, which may be varied from sterile to that typical of sewage plant effluents. Seeding with specific organisms also will be attempted.
5. Concentrations of ammonia, nitrite, and nitrate.
6. Variations in synthetic detergent concentrations.
7. Changes in anaerobic and aerobic conditions.

It is intended that biological data will include viruses as well as bacteria. During the initial stages of the project, biological information will be restricted to total bacterial count and coliform concentration.

After the project is under way and operating routinely, an effort will be made to include analyses of viruses. This phase of the project will be under the supervision of Dr. K.R. Johansson.

DISCUSSION

Sewage reclamation at the present time is becoming a reality and certainly will be continued and expanded in the future. Extensive research conducted by both universities and public agencies has demonstrated that sewage reclamation is feasible on a large scale if certain criteria can be met economically. The most feasible methods that have been proposed to the present time appear to be surface spreading or injection to the underground. Both methods use flow through the underground and depend upon subsequent pumping to make the waste water available for reuse.

The major problems encountered, or those that may be expected in a project wherein sewage plant effluent is charged to the underground, are (1) clogging of pores, thus decreasing the flow rate and/or increasing the head loss, (2) high concentrations of nitrate, and (3) excessive amounts of syndets. Additional problem constituents such as boron, phenols, heavy metals, viruses, etc., also may occur in certain instances. In this project attempts will be made to uncover basic information concerning the three major problems by analysis of the concentrations of the various constituents.

The clogging problem, which may be caused by several distinct processes including removal of suspended particles, precipitation of $CaCO_3$ resulting from a positive saturation index, biological growths, and changes in soil characteristics, will be studied in relation to the improvement noted in water quality. These data for various types of soil will aid in determining the degree and type of polishing treatment that should be applied to an effluent before it is allowed to pass to the underground.

Since biological degradation plays an important role in sewage reclamation, the possibility of maximizing the benefits of this degradation and minimizing the clogging resulting from the growths is a very practical problem that will be investigated.

The removal of syndets has been shown to occur in activated-sludge plants and is viewed as a biological phenomenon. If a mechanism is active in decomposing syndets in an aeration tank, the same mechanism also may operate in the underground. The proposed method of procedure will allow for the differentiation between adsorptive and biological removals.

Nitrates, which cause methemoglobinemia, present a problem in sewage reclamation. Denitrification is possible, and attempts will be made to determine the feasibility of using such a process in the underground.

SUMMARY

The research described in this paper is intended to provide further information about two important aspects of sewage reclamation by the pressurized recharge of aquifers: (1) the physical, chemical, and biological parameters of treated sewage that militate against recharge by clogging the interstices of soil near the well and (2) the changes in quality that occur as recharged sewage passes through soil of various types. It is an ambitious project that will probably uncover many more problems than it will solve, but at least it should shed some light on an aspect of waste water reclamation that is greatly in need of quantitative evaluation.

ABS IN GROUND WATER

R. H. Harmeson, Illinois State Water Survey

Surveys have been made in several areas of the nation to establish the concentrations of ABS in both surface and ground waters. During the summer of 1959, the Metropolitan Sanitary District of Greater Chicago made a study (1) of the Illinois Waterway from Chicago to Pekin, Illinois. The results of this study indicated that within the uppermost 50 miles of the waterway the concentration of ABS increased because of additions from the many communities located near the waterway. Downstream from this point, the processes of biological degradation, adsorption, and settling were such that concentrations of ABS in the river gradually declined despite additions by downstream communities. At the Franklin Street Bridge in Peoria samples showed that concentrations of ABS in the Illinois River ranged from 0.22 to 0.96 mg/1, with the mean concentration in all samples collected during June, July, and August, 1959, equalling about 0.52 mg/1.

The presence of ABS in the river at Peoria is of interest because, late in 1959, the local water company started withdrawal of part of its supply directly from the river. On an average, between 5 and 6 million gallons per day (mgd) of water are taken from the river into the newly erected surface water treatment plant. Of more interest in this discussion are the opportunities for the contaminant ABS to be transmitted from the river to the ground water supply. Ground water pumpage at Peoria in 1959 averaged 41.5. Ground water is withdrawn from three well fields, all of which are located near the river. ABS may be transmitted by natural infiltration methods to all three fields and by means of artificial recharge, which is used extensively in the North and Central Well Fields.

DESCRIPTION OF AREA

In the North Well Field, the water company operates a recharge pit near their main treatment and pumping station, which is located at the Narrows between the two lakes of the Illinois River. This pit is operated throughout the year. Within the same well field, a short distance downstream, a paper bag manufacturer intermittently operates another recharge pit. In 1959 the average daily recharge of these two pits was 42 percent of the average daily ground water pumpage (7.7 mgd) from the well field.

Farther downstream, in the Central Well Field, there are on State Water Survey property two recharge pits that are operated by the city only during the cooler months of the year. The Central Well Field is the largest and from it the greatest ground water withdrawals are made. Here, the average daily artificial recharge in 1959 was about 8 percent of the average daily ground water pumpage (28.5 mgd). Ground water gradients in this well field are normally southwesterly in direction from the recharge pits, roughly parallel to the river, and toward two pumpage centers: one at the Hiram Walker's distillery and the other near Commercial Solvents Corporation or the water company's Dodge Street Wells.

SURVEY METHODS AND ANALYSIS

The concentrations of ABS found in the Illinois River at Peoria indicated that information should be sought on the amounts of ABS being transmitted to ground water by artificial recharge methods.

From September 1959 to September 1960, samples of river water were collected weekly near the Peoria Water Works Company treatment plant and at the intake to the Water Survey's recharge pits. Ground water samples were collected in the Central Well Field from the Survey's Test Well No. 19, from several of Hiram Walker's wells, from the water company's Dodge Street wells, and from Commercial Solvents Corporation Well No. 7.

Test Well No. 19 is located within 90 feet of the Survey's recharge pits and about 400 feet from the river. Hiram Walker's Well No. 2 is 1000 feet from the pits and within 250 feet of the river. Hiram Walker's Well No. 5 is 1800 feet from the pits and 750 feet from the river. Commercial Solvent's Well No. 7 is 9600 feet from the pits and 2000 feet from the river. Because of variations in pumping schedules, it was impossible to collect more than 35 samples from either of the two Hiram Walker wells sampled.

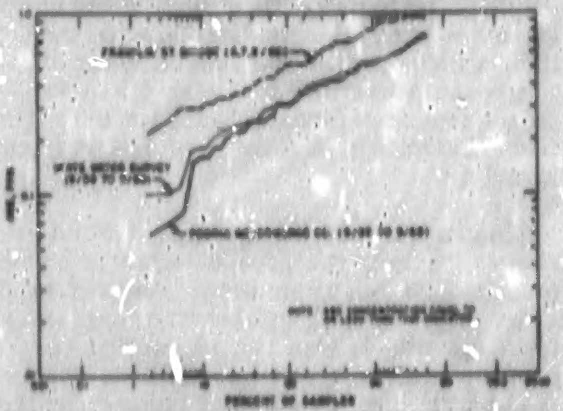

FIGURE 1. INDICATED ABS CONCENTRATION IN SAMPLES FROM ILLINOIS RIVER AT PEORIA

The concentration of ABS in samples was determined by the direct methylene blue extraction procedure. Reference standards were prepared from material containing 62.4 percent ABS.

RESULTS OF SURVEY

The determined ABS concentrations have been plotted on a logarithmic probability scale in Figures 1, 2, and 3. Table 1 shows the range and mean concentration of ABS found at the different sampling locations.

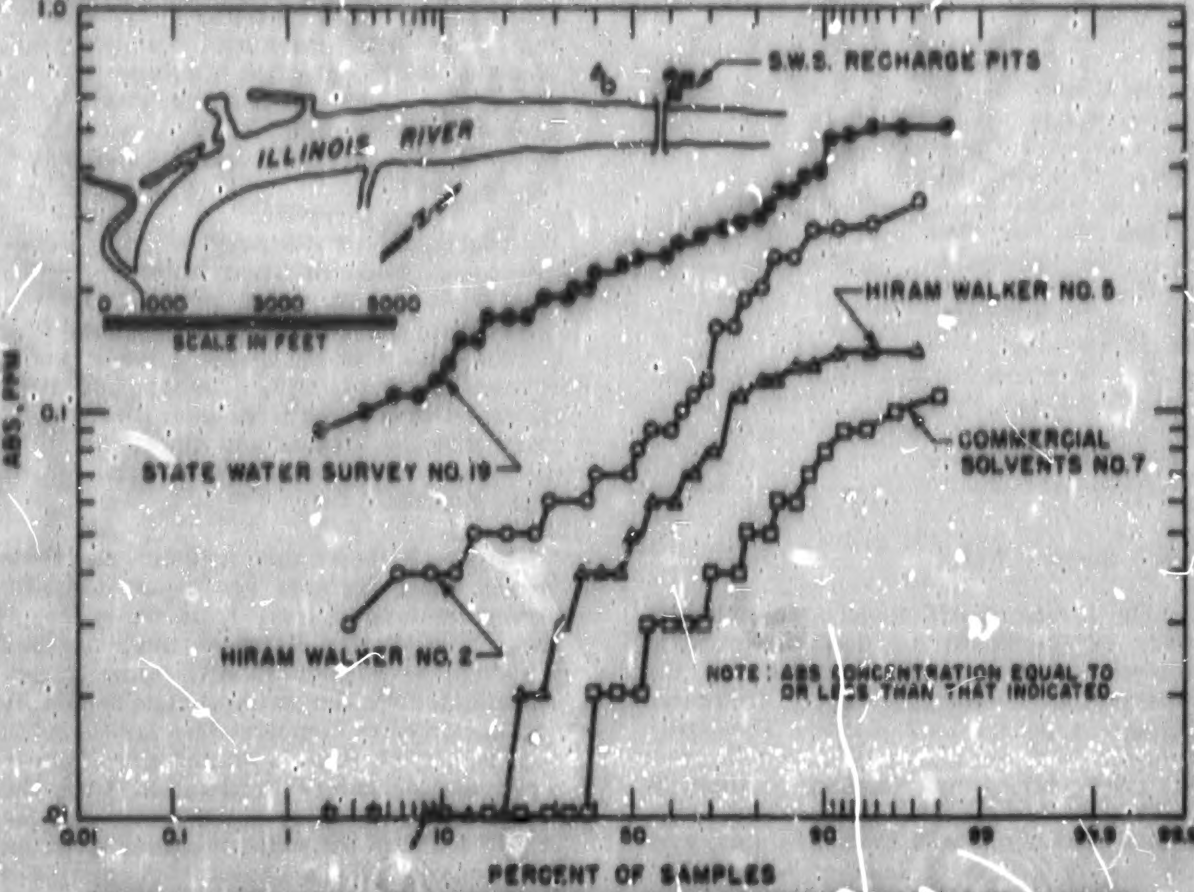

FIGURE 2. INDICATED ABS CONCENTRATION IN SAMPLES FROM GROUND WATER AT PEORIA

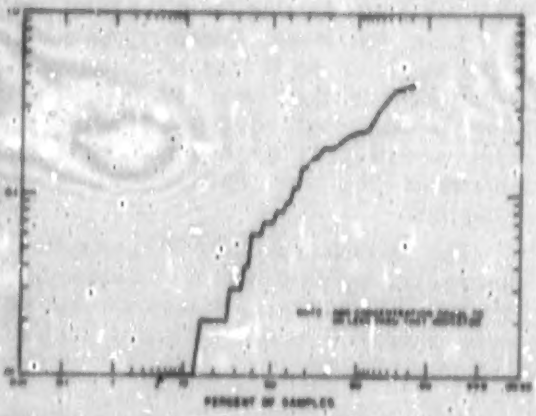

FIGURE 2. INDICATED ABS CONCENTRATION IN SAMPLES OF PEORIA TAP WATER.

Table 1. ABS CONCENTRATIONS AT SAMPLING LOCATIONS, PEORIA, ILLINOIS

Sampling Location	ABS, mg/l Minimum	Maximum	Mean
Illinois River-Franklin St. Bridge (June - August 1959)	0.22	0.96	0.61
Illinois River - SWS Laboratory (Sept., 1959 - Sept., 1960)	0.1	0.73	0.31
SWS Test Well No. 19 (Sept., 1959 - Sept., 1960)	0.09	0.51	0.24
Hiram Walker Well No. 2 (Sept., 1959 - Sept., 1960)	0.02	0.33	0.07
Hiram Walker Well No. 5 (Sept., 1959 - Sept., 1960)	0	0.14	0.05
Commercial Solvents Well No. 7 (Sept., 1959 - Sept., 1960)	0	0.11	0.02
Tap Water - Peoria Laboratory (Sept., 1959 - Sept., 1960)	0	0.40	0.07

ABS in Surface Water

The levels of ABS found in the Illinois River at Peoria during this survey were somewhat lower than those found by the Metropolitan Sanitary District of Greater Chicago in the summer of 1959. These differences were caused by the lower flows in the river during the summer of 1959. A rough correlation exists between discharge measurements and ABS concentrations, with ABS levels generally less at higher flow rates.

ABS in Ground Water

At sampling points more distant from the pits the ABS content may be lower as the result of adsorption on the soils of the aquifer, biologic action, and dilution by ground water. The samples collected during this survey showed that ABS concentrations in ground water are lower at greater distances from the recharge pits, but the relative controlling factors are not defined clearly.

Indications are that during artificial recharge periods the ground water near the pits in Well No. 19 is almost completely of river origin. During ground water movement from the pits to Well No. 19, about 25 to 30 percent of the ABS is removed from the recharged water. Crude experiments in the laboratory on the ability of native soils to remove ABS from recharged water have indicated that soils from the pit area may be expected to remove between 15 and 25 percent of the ABS transmitted through them. Because the concentration of sulfate remains practically unchanged from the river to the ground water in Well No. 19, it is assumed that ABS removal is primarily mechanical in nature.

The Public Health Service made a carbon filter study of river water and water from Well No. 19, which provided further evidence of the similarity between the two. Carbon filters were operated for a month during March of 1959. The organic contaminants recovered from those filters indicated that the amount and character of the materials in the two samples were essentially similar.

Figure 2 shows that further reductions in ABS concentrations are associated with movement farther away from the recharge pits. At the greater distances, the processes by which reductions in ABS concentration are effected are almost impossible to identify because they are complexed by variations in pumpage, by changes in ground water movement, and by natural infiltration from the river. The variability in the concentrations of ABS found in the wells at a distance from the recharge pits is shown by the nature of the curves in Figure 2. Of ground water samples collected from locations more than 1000 feet from the pits, 60 percent showed relatively insignificant ABS concentrations.

Because the Peoria water supply has become a mixture of treated surface water, artificially recharged water, and naturally infiltered ground water, samples of tap water at the Peoria Laboratory were analyzed to determine the concentrations of ABS that might be expected in the distributed supply. Figure 3 shows rather extreme variability in the ABS concentrations found and indicates that as much as 66 percent of them could be classified as insignificant.

SUMMARY

The Illinois River, which is the direct source of part of Peoria's water supply and which furnishes water for artificial recharge in two well fields, contains ABS.

ABS enters the water supply distribution system through the water treatment plant and from wells that obtain water from aquifers recharged from the river by either natural or artificial means, or both.

The concentrations of ABS found in samples of artificially recharged ground water have not been critical insofar as the requirements of the new Public Health Service Drinking Water Standards are concerned. As would be expected, the highest concentrations of ABS in ground water have been found near the recharge pits, and even here 94 percent of the samples analyzed were found to contain less than the recommended upper limit of 0.5 mg/l ABS. At distances of 1000 feet from the pits and beyond, no ground water samples were found to contain more than 0.35 mg/l ABS. And, in the Dodge Street wells, which supplied 5 of the total 23.4 mgd municipal supply for Peoria in 1959, the highest ABS concentration found in 26 samples was 0.03 mg/l.

Of more concern than the ABS concentrations found in these ground water samples is the probable presence of other undiscovered organic contaminants and the possibility that these other contaminants may increase in concentration as artificial recharge is continued. For instance, the chloroform soluble carbon filter extract (CCE) (2) from the one carbon filter run made by Public Health Service personnel showed 0.178 mg/l in the sample taken from Test Well No. 19. We don't know whether this has decreased or increased.

Additional studies of the organic contaminants transmitted to ground water are indicated. Most pressing are the needs for suitable methods for detecting and analysing ground water for organic contaminants.

REFERENCES

1. Hurwitz, E., et al. "Assimilation of ABS by an Activated Sludge Treatment Plant-Waterway System," Journal WPCF, 32:10:1111-1119, 1960.

2. Private communication with personnel of Robert A. Taft Sanitary Engineering Center, 1959.

GROUND WATER CONTAMINATION STUDIES AT THE SANITARY ENGINEERING CENTER

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Well water contamination by synthetic detergents has been reported many times in the literature within the last few years (1, 2, 3). Because of this development, the fate of these biologically resistant materials and their influence upon other contaminants have been of concern to many health officials. To determine the interrelationship of contaminants, soil types, dosing rates, and intervals, small-scale soil-column studies have been conducted at the Center since the spring of 1959. This paper will touch on the highlights of the work as it has been developed both in the laboratory and in the Pilot Plant Wing.

MOVEMENT OF COLIFORMS AND ABS IN GROUND WATER

The first experiment was confined to observing the influence of alkyl benzene sulfonate (ABS) on the movement of coliforms through a 10-foot water-saturated sand column. This seemed to be one of the most pressing problems and perhaps the easiest to tackle from an apparatus and operation standpoint. To further ease the complexity of the first experiment, an effort was made to use synthetic and thus reproducible solutions or suspensions, plus a soil (Chillicothe, Ohio, sand) that was essentially a clean silica sand normally sold for rapid sand filters. The characteristics of the feed water and disinfected sands used are presented in Tables 1, 2, and 3. The concentrations of pure ABS in the sand were usually at or below 10 mg/l, and the number of fresh coliforms introduced daily with the 1 liter of de-ionized water ranged from 10,000 to 20,000 per ml. Chlorides, 100 mg/l, also were introduced to check the water flow-through time. Since it was thought that total time of contact as well as flow rate (0.3 fpd) within the soil might have influence on the survival or persistence of ABS or coliforms, a 10-foot column length was selected, and thus there was a 35-day holdup time within the Chillicothe sand column.

Two of the three 6-inch-diameter columns of sand were used as controls to indicate the movement of ABS or coliforms without the other contaminant present, and the third column was for tests with the mixed contaminants.

Samples were collected at 1- to 2-foot intervals, first to check the chloride front, and later ABS and coliform levels.

ABS traveled through both columns of clean Chillicothe sand about half as fast as chlorides but arrived at any depth much sooner than coliforms. The organisms did not penetrate beyond 2 to 4 feet in the 67 days of the first test, and 10 mg/l ABS did not influence significantly the arrival time or concentration of coliforms.

Table 1. DAILY FEED WATER CHARACTERISTICS [a]

	Newtown sand (7/60 to 9/60)		
Characteristics	Column 1	Column 2	Column 3
pH	6.7-7.3	6.7-7.3	6.7-7.3
Alkalinity, mg/l	2-6	2-6	2-6
Peptone, mg/l	0	50	50
COD, mg/l[b]	0	50	50
ABS, mg/l (avg with std deviation)	9.65 ± 1.2	9.45 ± 1.2	0
Chlorides	[c]	[c]	[c]
Coliform per ml (avg)	0	17,000	12,500
Flow rate, fpd (1 fpd or 0.67 ml/min)	0.4	0.4	0.4
Temperature, °F	From 68-90,	Room Temperature	
Free chlorine residual	Trace	0	0

	Newtown sand (7/60 to 10/60)		
	Column 4	Column 5	Column 6
pH	6.7-7.3	6.7-7.3	6.7-7.3
Alkalinity, mg/l	2-6	2-6	2-6
Peptone, mg/l	0	50	50
COD, mg/l	0	50	50
ABS^{35}, mg/l [b] (avg)	10.9	10.8	0
Chlorides	[c]	[c]	[c]
Coliform per ml (avg)	0	18,300	12,600
Flow rate, fpd	0.6	0.6	0.6
Temperature, °F		68-90	
Chlorine residual	Trace	0	0

[a] Similar water fed to columns with Chillicothe sand (3/59 to 6/59).

[b] Sampled daily.

[c] 100 mg/l chlorides fed to all columns first 4 weeks.

Table 2. PHYSICAL CHARACTERISTICS OF CHILLICOTHE AND NEWTOWN, OHIO, SANDS

Characteristics	Chillicothe	Newtown
Effective size, mm	0,38	0,18
Uniformity coefficient	1,37	1,8
Specific surface area (estimated), cm^2/g		
Sieve analysis	49	110
Stearic acid adsorption analysis	268	2048
Porosity as placed, %	52	43

Since some ABS seemed to be retained on the sand, the second experiment was conducted with a much finer sand so that the influence of surface area on the removal of both ABS and coliforms could be checked. This sand, obtained at Newtown, Ohio, was remarkably different in another way. It had a 17.6 percent loss on ignition at 700°C, due almost entirely to calcium and magnesium carbonates, and thus was quite soluble in the low-buffered feed water.

After 417 days the ABS level in the effluent of the Newton sand filter was still not up to 10 mg/l. Indications were that negative chemical interferences were causing this depression at all depths so the experiment was stopped. A material balance for ABS was then sought by extraction of the material from small representative portions of sand at 2-foot intervals. Initially, recovery was poor; however, radioactive sulfur-35 was used subsequently in the ABS (ABS^{35}), and thus some of the interferences experienced with the methylene blue analytical procedure were eliminated. The ABS was extracted off the sand in three 8-hour periods (instead of one) and recovery was good. It was then apparent that this Newtown sand had a much higher capacity (10-20 ug/g) for retention of ABS than the Chillicothe sand, which retained only about 3 ug per gram.

Table 3. SUMMARY OF CHEMICAL ANALYSIS OF OF SANDS

Constituent	Percent of air-dry weight	
	Chillicothe	Newtown
Moisture at 110°C	0,021	0,115
Loss on ignition at 700°C	0,144	17,57
Carbon	0,050	0,20
Organic matter	0,087	0,34
Nitrogen (N)	-	0,004
Phosphorus (P_2O_5)	0,0041	0,013
Potassium (K_2O)	nil	0,47
Sodium (Na_2O)	nil	0,34
Silica (SiO_2)	97,30	50,72
Iron (Fe_2O_3)	0,155	1,85
Aluminum (Al_2O_3)	1,99	6,27
Titanium (TiO_2)	0,038	0,17
Calcium (CaO)	0,127	14,8
Magnesium (MgO)	0,040	8,20
Sulfate (SO_4)	0,165	0,422
Chloride (Cl)	0,003	0,010
Carbonates (CO_3)	0,007	16,0
Summation [a]	99,908	98,316
Acid solubility (AWWA Std Method)	0,33	40,4

[a] Major elements expressed as oxide plus percentage moisture and loss on ignition.

Static tests conducted in beakers and intermittently operated flow-through column studies both indicated that the retention of ABS on Newtown sand was also very time dependent. Equilibrium, for instance, was not reached in 28 days of static tests. Therefore, hydraulic rate will influence greatly the arrival time of 1 mg/l ABS in this sand. To illustrate this point, other runs were made at 6, 3, 1.5, and 0.8 feet per day instead of 0.4 foot per day, and the arrival times did decrease.

During the 417-day run with Newtown sand at 0.4 foot per day, the coliform organisms did not penetrate much beyond 6 feet. Flows of 0.8 foot per day did decrease the arrival time at 4 feet from 114 days to 82 days, but in both runs the presence of ABS caused no significant difference in the arrival time or in the concentration of coliforms (see Table 4).

Conversely, the coliforms and a few protozoa did not alter significantly the concentration of ABS. At one point, when all the ABS could not be accounted for, there was some thought that this deficit was partially due to biological degradation; however, the parallel control column with its sterile solution of ABS^{35} showed the same level of ABS as the seeded column. Furthermore, the fate of the S^{35} used in making up the ABS was followed throughout the run and it was possible to demonstrate that no significant splitting off or formation of byproducts containing S^{35} occurred.

To further check the adsorption variation of ABS with different soils, static tests were conducted with two reference clays, two Long Island sands, calcium carbonate, and one highly organic soil. Preliminary results indicate that the clays did not take on ABS in proportion to their surface area; however, the soil with 20 to 24 percent organic matter did retain about 100 times more ABS than clean sand. This soil has a specific surface area about 100 to 200 times that of the sands.

These results suggest that perhaps the place and frequency of dosing these contaminants into the ground may have a lot to do with buildup of organic solids, and thus retention of ABS. This prompted work on the unsaturated regions of the ground and on the influence of rate and frequency of dosing.

Table 4. ARRIVAL TIME IN DAYS FOR COLIFORM [a] AT VARIOUS LEVELS IN SAND IN AN UPFLOW COLUMN WITH OR WITHOUT ABS PRESENT

Distance, ft	Chillicothe sand (Flow rate, 0.3 fpd)		Newtown sand (Flow rate, 0.4 fpd)		(Flow rate, 0.8 fpd)		(Flow rate, 0)
	ABS	No ABS	ABS	No ABS	ABS	No ABS	ABS
0.5	-	-	-	-	9	9	0
1	6	11	16	15	41	41	0
2	68	62	63	70	68	69	
4	69	60	114	114	82	82	
6			196	201	119	119	
8			417	417			
10							

[a] When at least 2 coliform per ml showed up in a liquid sample and feed water contained 10,000 to 20,000 coliform per ml.

FATE OF ORGANICS AND COLIFORMS IN SEEPAGE BEDS

A 3-foot-diameter column with 4 feet of Newtown sand and gravel was arranged to simulate a subsurface disposal system that normally is used to handle a septic tank effluent. This column was dosed each day with 5 gallons, all within 25 minutes, of septic tank effluent containing about 10 mg/1 ABS.

After 9 months of operation, no ABS was present in the effluent and only 1 to 10 coliforms per ml had appeared during the eighth month. During passage through the bed, ammonia was converted to nitrates, practically all suspended solids and BOD were removed, some color persisted, and the COD was reduced 90 percent. Within this time 60 grams of ABS was put into the bed; this means that approximately 60 µg of ABS was retained on each gram of soil-slime mixture, or 4 to 5 times more than on Newtown sand alone.

Ponding in the subsurface gravel bed indicated that clogging was progressive but not rapid. The ponding during dosing reached a point of temporary failure in about 300 days. Dosing has been accelerated to speed up the passage of ABS and coliforms and to achieve a complete clogging of the bed. Indications from these results are that the dosing cycle or a rest period to provide aeration may be important if the soil is to be used to the utmost. In further tests, therefore, other similar 3-foot columns will be used and the dosing rate and pattern varied, even to the use of spray irrigation. Various types of soils, bed depths, and radioactive-tagged organic contaminants will be used in future studies so that the usefulness or limitations of soil as a means of disposal of new as well as old pollutants can be predicted.

VIRUS MOVEMENT IN GROUND WATER

It would have been desirable to have included virus in all the experiments discussed, but unfortunately this was not possible, since the normal die-off in a week or month is too high to make an experiment lasting 25 to 35 days meaningful.

A separate apparatus, therefore, was set up to determine the fate of Type I polio virus in ground water that is moving slowly through sand. Since about 10 percent of these 10,000 to 30,000 virus units per ml die in 24 hours, a flow rate of 3 to 4 feet per day was selected so that the water would pass completely through a 2-foot bed of sand in less than a day. Parallel columns of Newtown and Chillicothe sand were used for these studies also.

Initial runs indicated very little passage of polio virus in 50 hours. It then seemed necessary to see if there was a saturation point where the capacity of the sand to hold virus would be exceeded. For this part of the study the virus suspension was mixed with the seepage bed effluent described in the previous section. After survival studies indicated the Type I polio virus count would remain reasonably high for 1 day in this waste water at room temperature, a continuous feeding of 10,000 to 30,000 virus units was started upflow through both sand columns. A fresh virus suspension was made up each day. The first appearance of 1 to 12 virus units in the effluent did not occur until flow had continued for 6 weeks in the Chillicothe sand and for 15 weeks in the Newtown sand; in fact, the virus count has not changed significantly in 6 months of continuous feeding.

Future plans are to check the influence of ABS, hydraulic rates, and soil types on movement of viruses through unsaturated and saturated zones. These studies may give some indication of removal mechanisms.

SUMMARY

Studies of small flow-through sand columns indicated that 10 mg/l ABS has no significant influence on the survival or movement of coliforms through homogeneously packed sand that is water saturated.

The retention or movement of ABS in some soils was shown to be related to specific surface area, time of exposure, and perhaps to organic content.

The survival or movement of 10 mg/l ABS in a water-saturated sand is not altered significantly by the presence of coliforms.

The point and manner of discharging waste waters into the ground appear to be important in the disposal of biologically resistant materials; therefore, much more laboratory and field research is needed in this area.

REFERENCES

1. Flynn, J., Andreoli, A, and Guerrera, A., "Study of Synthetic Detergents in Ground Water," Journal AWWA 50:1551 (Dec. 1958)

2. Deluty, Jerome, "Synthetic Detergents in Well Water," Public Health Reports, 75:75 (1960)

3. Walton, Graham, "Effects of Pollutants in Water Supplies - ABS Contamination," Journal AWWA 52:1354 (Nov. 1960)

RESEARCH IN GROUND WATER HYDROLOGY AND ITS RELATION TO NUCLEAR ENERGY WASTES

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Present research in ground water geology and hydrology, sponsored by the Atomic Energy Commission, is largely concerned with the movement of radionuclides into the subsurface where they constitute a potential source of ground water contamination. A substantial part of the research to date has been composed of laboratory model studies, analog models, and other theoretical and mathematical studies. Many of these studies have provided us with improved understanding of the microhydrogeologic aspects of ground water movement, both above and below the water table. These include (1) mechanisms of dispersion below the water table, (2) range of rates of movement of ground water through a heterogeneous aquifer, and (3) factors affecting spreading and downward percolation of water in the zone of aeration. Although our understanding of these problems is far from complete, it is possible to apply our present knowledge to actual field situations. When more accurate and complete field information is obtained, we can further evaluate the adequacy of the analytical tools, such as models, computers, and equations, in our ultimate aim to predict what happens under various hydrogeologic situations. If our laboratory and theoretical studies do not enable us to predict adequately hydrologic and geochemical processes and phenomena, we are not likely to remedy these deficiencies until we take a closer look at a number of different specific mesohydrogeologic settings in the field. Our inabilities stem as much from our lack of understanding and inadequate definition of these natural settings as from our present knowledge of man-made models and formulae.

Local Studies

Recent work by Bierschenk is sufficiently descriptive of the subsurface mesohydrogeologic framework at Hanford that his analysis of the data begins to give a good local picture of the directions and rates of ground water movement at that site. At least, in a general way, we can predict what effect certain external influences such as increased water inflow may have on ground water movement and on the movement of radioactive waste constituents that have been disposed of at Hanford.

Dr. W. J. Kaufman at the University of California has tested the behavior of different labels that may be used in hydrogeologic investigations where the effects of density, temperature, and exchange or sorption phenomena are important. His work has included the injection of several different tracers into a well-described, thin, confined aquifer in conjunction with a skillfully planned and engineered well field. These studies are directly indicative of behavior only under the specific mineralogic, sedimentational, and hydrodynamic, conditions, including porosity, permeability, and head distribution, where the tests were conducted. Their application elsewhere is limited to the extent that other areas may resemble the hydrogeologic regimen where these tests have been made. This qualification does not diminish the value of these studies. Recognition of the limitations of this or other work is necessary to derive maximum transfer value when other environments are considered.

At the National Reactor Testing Station in Idaho, the U. S. Geological Survey is studying the movement of wastes in the zone of saturation downgradient from a disposal well at the Idaho Chemical Processing Plant. The movement of wastes below the MTR-ETR (testing reactors) effluent seepage basin also is being studied. This second phase involves the downward percolation through joints and other fractures in the basalt to the regional water table, which is more than 450 feet below land surface. Here are some of the questions:

1. How much opportunity do dissolved constituents moving through a highly fractured basalt, such as that in the Snake River Plain, have to come in close enough contact with the formation material for exchange reactions to take place?
2. What kind of exchange sites are available on or near the surface of the fractured basalt blocks, and how effective will they be in removing radionuclides from circulation or in delaying the movement of these radionuclides?
3. What fracture pattern or randomness exists in the basalt, and what is the distribution, extent, and nature of the joints and other fractures?

Tritium

One of the most promising labels for use in hydrologic research is tritium. As an isotope of hydrogen, it combines with oxygen and can move anywhere water or water vapor will move. Because of its density, however, it tends to be subject to isotopic fractionation. Thus it is difficult to determine how frequently or how many times it might pass from liquid to vapor phase while moving through a given portion of the zone of aeration. The possibility of repeated transition between the liquid and vapor phases may limit the usefulness of tritium in soil moisture studies, at least until the behavior of tritium under natural conditions can be defined more fully than it has been to date. The use of tritium in environmental studies involving ground water in the zone of saturation appears to be quite advantageous, and further research and development along such lines seems warranted.

Chromatography

The investigations at Hanford, Oak Ridge, and the Savannah River Plant have shown that particular nuclides move more freely than others in one environment, but in some other geologic and hydrologic setting a particular nuclide may be the more or less mobile. Some generalizations are possible, and the more fundamental ones are well known.

Information has been developed on the behavior of strontium, cesium, ruthenium, iodine, and some other elements that occur as radionuclides in nuclear wastes. Prout's work at the Savannah River Plant and that of Tamura and Jacobs at Oak Ridge National Laboratory are notable. Also work by Naeser, May, Carroll, Schnepfe, and Barker, of the Geological Survey, has contributed to the knowledge of sorption of radionuclides on different minerals, including kaolinite, vermiculite, glauconite, montmorillonite "illite," ORNL soils, etc.

The Chemical Effluents Technology group of Hanford Laboratories, the University of North Carolina, the U. S. Geological Survey at Washington, D. C., and Denver, the Oak Ridge National Laboratory, the University of California, and groups at the Savannah River Plant and at Los Alamos, are engaged in investigations related to ion exchange and fixation of radionuclides in mineral substances and in studies of chromatographic segregation of radionuclides by sorption processes. Some of this work is an effort to establish decontamination processes to be used before discharge of wastes to natural environments. Much more understanding is needed of the chromatographic processes in natural formations and aquifers, both above and below the water table. This understanding would enable a better assessment of the burden that can be borne safely by different natural environments, to assure against the spread of hazardous concentrations of radionuclides from waste disposal operations. This area presents an exceedingly complex series of problems and a wide variety of factors, including changing pH, temperature, mineralogy, and rates of flow. Professor Henry Thomas, at the University of North Carolina, has outlined a long series of experiments that need to be made in this field and that should be a challenge to any research-minded chemist or geochemist.

Hydrodynamics

Work by E. S. Simpson on the mechanics of dispersion will be helpful in furthering our quantitative understanding of the dispersal process, which has been a controversial problem. Most theories, formulae, and early quantitative studies did not recognize fully the multiple dividing and redividing of flow lines during the movement of ground water through granular porous material. H. E. Skibitzke has also worked on this problem and has determined an angle of dispersion of about 6 degrees in homogeneous sand models cemented with epoxy resin. Skibitzke used phosphorous-32 as a tracer, introduced at the point source. In actual field situations, Bierschenk's work at Hanford in glacio-fluviatile deposits indicates a dispersion angle of as much as 30 degrees in this heterogeneous material. It is likely that the included angle might be as much as 60 degrees from the point source "injection" well. Work at the National Reactor Testing Station may show even wider dispersion in the highly fractured Snake River basalt. The spread may be so great in some situations that a question might be asked as to whether it should be called dispersion or simply spreading - especially if it is possible that some turbulent flow is taking place in these aquifers where previously all flow was assumed to be laminar. Other possible semantic solutions could class wide dispersion as "channeled permeability" or "divergent paths of preferred permeability." The result is wide dispersal through possibly much larger volumes of earth material than had earlier been recognized. This, of course, leads to the consideration of selective sorption and desorption phenomena. It must be recognized immediately that the involvement of large volumes of earth material does not necessarily yield correspondingly large decontamination factors due to sorption. The reason is that the surface areas available for such reactions are much less in a permeable material than in tighter and finer grained materials. It is established that sorption decreases exponentially as flow rate through the exchange media increases. To better understand these chemical relationships and to arrive at an integrated picture of the field implications of ion-exchange - sorption - Kd relationships in natural heterogeneous terrains, we must develop a more comprehensive classification of permeable earth environments. A step in this direction was made at the American Association of Petroleum Geologists symposium on classification of sandstone bodies at the April 1960 meeting in Atlantic City. This symposium consisted of a series of papers describing the shape, size, distribution, and mineralogic and permeability characteristics of several types of sandstone occurrences. More work of this sort is needed, and it should be extended to other types of formation materials.

Heterogeneity

Skibitzke of the U. S. Geological Survey in Phoenix has recognized many of the hydrologic implications of the heterogeneous nature of earth materials. Recent patterned models of heterogeneity made by Skibitzke show in a graphic qualitative way what profound influences bars or stringers of more or less permeable material in a sand model can have on the movement of fluids through the model.

Other model studies by Paul Rowe at Hanford and Palmquist of the U. S. Geological Survey at Denver will shed some light on problems associated with the movement of water in the zone of aeration. The field implications of much of this work cannot be evaluated fully, until natural materials are used and quantitative studies are made on real wastes in the field. Thus the studies at Los Alamos, Hanford, the National Reactor Testing Station, Oak Ridge, and the Savannah River Plant are essential to the evaluation and finally to the prediction of how certain waste liquids will behave in these various hydrogeologic terrains. Through such studies it should be possible to assess the potential of ground water contamination in a given setting, but this can only be done when enough different settings have been studied that they can be classified. The greater the integrity of the classification, the more accurate the predictions can be. The efforts of the involved disciplines must be guided toward an understanding of the relationships between the geochemical phenomena and the physical environmental factors of permeability and particle size distribution.

A general approach to a study that would ultimately lead to the classification of an environment into a well-defined category must include the following:

1. A geologic study to delimit the porosity, permeability, mineral and fracture pattern distribution, and the structural stratigraphic influences. This establishes the textural and mineral framework on which changing parameters may be based.

2. Hydrologic determination of head distribution and its relationship to the porosity, permeability, and mineralogy described previously.

3. Chemical determinations of (1) ion-exchange sites and their availability in terms of the porosity or permeability framework, (2) the effects of changing pH on the exchanged or sorbed ions, (3) sorption of ionized and unionized substances in suspension, (4) cations versus anions in competition for available exchange sites, and (5) the ultimate hazard.

These various reactions and processes must be considered in terms of dilute radiometric quantities, in contrast to earlier thinking in terms of chemical quantities. The degree of cleanup and decontamination efficiencies generally desired are several orders of magnitude greater than with other conventional industrial wastes.

This same philosophy applies to the geologic and hydrologic studies in a somewhat different way. In most standard mineral and hydrologic investigations in the past, averages of porosity, permeability, and mineralogy have been sufficient, but for specific ground water contamination problems, averages may no longer be adequate. They constitute an essential step, however, in reaching the more quantitative values now needed. Actual distributions of minerals, pore space, and permeabilities and their preferred orientations, if developed, are necessary to an understanding of the hydrodynamics and chemical processes that take place in the framework. Determination of maximum as well as average rates of movement of ground waters has become much more important, particularly in consideration of the decay times of nuclides that are common constituents in nuclear wastes.

Thorough description of the geologic, hydrologic, and chemical parameters mentioned above is the first step in the process to describe, classify, predict, and verify the movement of ground water contaminants. Tools for description are good for past needs but marginal to inadquate for present and future needs.

New "tracer" techniques may be extremely valuable in some areas after tried and true descriptive tools such as well log analysis, subsurface geologic exploration (including bore-hole geophysics), standard pumping tests, and water table or piezometric map preparation and evaluation have been undertaken. Tracers will not yield magic answers to ground water problems, which too often are a result of a lack of understanding of the geologic framework in which the water moves, until we do something through more or less conventional means to improve the fundamental knowledge.

Field studies are needed to better describe the hydrogeologic fabrics. Improved field instruments and techniques are needed. A bore-hole pulse height analyzer would be helpful in measurements of the movement of radionuclides in the ground and in ground water in the field. Such an instrument would have value as a geochemical research tool for field applications as well as for obvious and important routine monitoring applications. Instrument development is not a specific job for the hydrogeologist or the geochemist; however, they can state the needs, requirements, and perhaps even the specifications for new instruments and techniques. Then the instrument companies can pursue the development and furnishing of these new tools.

CONCLUSION

Some environments are described well enough that some steps can be taken toward their classification. Rarely is the degree of the classification sufficient to predict very precisely the hydrologic and geochemical processes, little more than empirical verification has been achieved along the lines of the combined and refined approach that is needed in environmental and sanitary engineering studies to assure long-term environmental safety in the development of nuclear energy. The nuclear wastes are unique, since they have allowable concentrations much lower than those dealt with in the past; thus, much sharper methods of environmental analysis are needed. This should not imply however that ground disposal of certain types of radioactive wastes cannot be continued safely under proper environmental conditions and adequate operational and control procedures.

GROUND WATER CONTAMINATION RESEARCH AND RESEARCH NEEDS OF THE LOS ANGELES COUNTY FLOOD CONTROL DISTRICT

A. E. Bruington, Los Angeles County Flood Control District

The Los Angeles County Flood Control District has a dual responsibility, flood control and water conservation. Inasmuch as Los Angeles County is located in a semiarid region with a mushrooming population, water conservation is of prime importance and, as water demands grow, numerous problems are encountered. Many of these problems are associated with the overdraft of the ground water supply and are combated through the following means: (1) replenishment of the ground water basins with local water (storm runoff originating on tributary streams), (2) replenishment of the ground water basins with imported water (water originating outside of the local area), and (3) replenishment of the ground water basins with reclaimed waste water. To provide the basis for planning such programs, data are collected on ground water quality and ground water levels. Thus, ground water contamination problems with which the District concerns itself are those associated mainly with water conservation.

SEA WATER INTRUSION

Pumping overdrafts in past years, to supply increasing agricultural, domestic, and industrial demands, coupled with a 17-year period of dry years have lowered ground water elevations far below sea level in coastal areas of Los Angeles County. This has reversed the historical seaward hydraulic gradient, causing extensive damage from sea water intrusion into the coastal ground water basins, with resultant large economic losses.

In the Santa Monica Bay area of the County, sea water intrusion caused the abandonment of wells as early as 1920. Through the years, fresh water wells continued to be abandoned, and by 1952 sea water had completely contaminated one of the main aquifers some 2,000 feet inland from the ocean. More recently sea water intrusion has been detected in other coastal aquifers in the San Pedro Bay area of the County.

Research

In 1952, Manhattan Beach, in the Santa Monica Bay area, was chosen as the site for a cooperative test between the State of California and the Flood Control District to determine the effectiveness of preventing further sea water intrusion by creation of an artificial fresh water mound that would be sufficient to halt the landward movement of sea water. Briefly, the test consisted of nine recharge wells, spaced about 500 feet apart, paralleling the coast and located about 1/2-mile inland, through which a total of about 4.5 cfs of treated Colorado River water was injected continuously during the initial stages.

The barrier effect of the fresh water mound was attained, as expected from theoretical considerations. This prompted the District to continue operation of the project.

The project has now been operating for 8 years and has injected over 27,250 acre-feet of treated Colorado River water. With the present total of 12 operating wells, the project protects about 1-1/2 miles of coast line from further sea water intrusion. It is planned to expand the facilities so that by 1966 the entire 11-mile reach along the southern Santa Monica Bay coast line will be protected from further sea water intrusion.

Studies also are under way to determine requirements for affording similar protection to the affected areas in the vicinity of San Pedro Bay.

IMPORTED COLORADO RIVER WATER

About one-half of all water used in Los Angeles County is derived from wells; the remainder is imported from the Owens Valley of California by the City of Los Angeles and from the Colorado River by the Metropolitan Water District of Southern California.

Since 1954, the Los Angeles County Flood Control District has been purchasing untreated Colorado River water for spreading in stream beds and off-channel spreading grounds (shallow basins located in permeable areas) to replenish ground water storage shortages resulting from an accumulated overdraft currently estimated at about 1,000,000 acre-feet. Since July 1960, the rate of replenishment has been approximately doubled by the initiation of more intensive replenishment efforts by the Central and West Basin Water Replenishment District.

To date, approximately 475,000 acre-feet of Colorado River water has been purchased and used to replenish the ground water basins in this program. During the 7-year period the imported water stored underground represented from one-fourth to one-half of the supply to the ground water basin.

Research

At the time the program of replenishment was begun, the question of the effect on the quality of the native water arose, since the native water is of higher quality than untreated Colorado River water. This is exemplified by the total dissolved solids, 350 ppm versus 725 ppm. A program of well sampling was started, designed to aid in determining the extent of degradation that might occur from using untreated Colorado River water for replenishing ground water storage.

After 7 years of operation, no significant change in water quality has been noted outside the immediate vicinity of the spreading grounds. (For the purpose of this study, "immediate vicinity" is defined as being within one mile of the spreading areas.) Three possible explanations for this are suggested: (1) insufficient time for the imported water to have traveled to and affected the water quality in areas an appreciable distance from the spreading areas, (2) diluting effect due to additional spreading of local storm waters that contain an average of 150 ppm total dissolved solids, and (3) removal, by pumping, of a large portion of the imported water before it has had an opportunity to diffuse and mix with local waters. A combination of these factors seems to have prevented any significant degradation of the ground water quality; however, more definite conclusions may be reached as the testing is continued.

WASTE WATER RECLAMATION

The District has conducted several tests related to waste water reclamation. Two tests, conducted in 1948 and 1949, were concerned with the surface spreading of secondary effluent from sewage treatment plants. It was found that alternate wetting and drying of spreading areas would provide an economical means of handling a fairly well-stabilized effluent and that percolation through 7 feet of unsaturated sand and gravel was sufficient to remove bacterial contamination.

Hyperion Studies

A large-scale test was conducted at the City of Los Angeles' Hyperion Sewage Treatment Plant over a 37-month period ending in January 195[illegible]. It included studies of tertiary treatment of sewage and of injection of treated sewage.

A method of percolating high-rate activated-sludge effluent through the uniform dune sand at the site was tried and found to be satisfactory. Briefly, the method consisted of percolating the effluent in spreading basins at rates averaging 0.5 to 1.0 cfs per wetted acre on a cycle of 1 hour of flooding to 5 hours of drying (or 0.25 to 0.5 foot of depth during each flooding) in order to properly provide aeration to the soil. A limiting factor in this method is that sufficient area must be available.

The best high-rate treatment method found was one using standard-rate activated-sludge effluent in a conventional rapid-sand filter. The effluent averaged 6.5 ppm suspended solids and 2.4 ppm BOD during one 7-week run, representing reductions within the filter of about 50 percent. The capacity of this process was upwards of 200 acre-feet per acre per day, and the estimated cost for tertiary treatment, including pumping to a 300-foot level and chlorination, was approximately $20 per acre-foot.

Another part of the test consisted of the investigation of the suitability of injecting, through recharge wells, reclaimed waste waters into aquifers of gravelly sand that were completely degraded from sea water intrusion. From this portion of the test it was concluded that: (1) Tertiary treatment of sewage treatment plant effluent is essential for successful well injection, (2) reclaimed waste water with a maximum limit of approximately 10 ppm suspended solids content (primarily organic) is believed to be acceptable for well injection, (3) injection of reclaimed waste water and its percolation through short reaches of aquifer further reduced concentrations of volatile acids, organic nitrogen, ammonia, nitrate, nitrite, chemical oxygen demand, and bacteria. Whether the rate of reduction would continue over long periods or for longer percolation paths is not known.

Supplemental Hyperion Tests

Supplemental tests at the Hyperion site will be commenced about June 1, 1961. In the previous test it was not practical to inject the rapid-sand filter effluent into the test recharge well. The goal of the supplemental tests is to determine more conclusively that large-scale rapid-sand filtration of standard-rate activated-sludge effluent will be satisfactory tertiary treatment of sewage for injection through recharge wells. In addition, it is planned to obtain additional information on the underground movement of such constituents as detergents, bacteria, nitrates, toxic metals, and perhaps viruses.

Water Quality Requirements for Injection of Reclaimed Waste Water

At the present time "sewer wells" are prohibited by law in California, but the State Health Department has agreed to support amendments to incorporate regulations that would permit ground water replenishment through injection wells by requiring that: (1) the chemical quality of water withdrawn from the underground formation meet current Public Health Service "Drinking Water Standards" and be free from other harmful and undesirable trace elements, (2) a positive control be maintained over the raw sewage chemical quality, (3) geological and hydrological data are available that support calculations to demonstrate a definite time of travel and definite degree of dilution of recharged wastes in natural occurring waters within the zone under the political or legal control of the recharger (as a corollary there must be positive control of withdrawal of domestic water supply from within the zone), and (4) the anticipated chemical quality of the water to be recharged is acceptable.

Whittier Narrows Demonstration Waste Water Reclamation Project

In about 1 year's time deliveries will be commenced from a 10-million-gallons-per-day waste water reclamation plant to be located in the Whittier Narrows area of Los Angeles County. This project is possible through the joint efforts of the Los Angeles County Sanitation Districts, the County of Los Angeles, the Central and West Basin Water Replenishment District, and the Los

Angeles County Flood Control District. The County of Los Angeles will pay the cost of constructing the plant, estimated at $1,700,000, and will be reimbursed, without interest, from the sale of reclaimed waste water; the Los Angeles County Sanitation Districts will construct and operate the plant; the Central and West Basin Water Replenishment District will purchase the reclaimed waste water; and the Los Angeles County Flood Control District will spread the reclaimed waste water in its nearby spreading areas for ground water replenishment. An important feature of the project is the availability of capacity in downstream sewers for solids extracted in the treatment process and for the flow capacity of the plant if the treatment process should become upset.

Project Goals

The goals of the project are: (1) to demonstrate the feasibility of such a project and (2) to encourage the construction of other plants to recover larger amounts of water for reuse at Whittier Narrows as well as at other locations in the County of Los Angeles.

CONTAMINATION BY REPLENISHMENT FROM STORM WATERS

The sporadic nature of storms bringing significant rainfall to Los Angeles County presents the danger that contaminating materials may be washed into streams at the same time that large quantities of runoff are available for conservation.

The problem may be accentuated by the modern day use of numerous insecticides and fungicides in agriculture and by exotic chemicals in industrial processes, where rainfall and runoff act as a vehicle to carry contaminants to the ground water basins.

Research

The District has conducted two studies of storm runoff, the first covering the storm seasons of 1931-32 and 1932-33 and the second the storm season of 1957-58. Both studies gave essentially the same results, indicating that valley runoff carried a slightly higher amount of unstabilized organic matter than water from the mountain watersheds but that both carried a high amount of dissolved oxygen.

Future Plans

It is planned to continue surveillance of storm waters through a program of sampling and analysis every 5 years.

SUMMARY OF RESEARCH NEEDS

As noted, many of the research needs of the District are for projects unique to Los Angeles County or, perhaps where interest has not yet been aroused, to other parts of the country. In the field of underground travel and fate of contaminants, the need to initiate projects to inject reclaimed sewage will require that considerably more information be obtained on long-time and long-distance effects of percolation in saturated aquifers of such contaminants as those contained in reclaimed sewage as viruses, detergents, nitrates, and toxic metals.

Of importance in planning replenishment programs is detailed information on the rate and direction of travel of ground water flow. Continued efforts are needed to develop acceptable economical ground water tracers that will endure for long periods and over long distances.

RESEARCH NEEDS IN GROUND WATER POLLUTION

J. E. McKee, California Institute of Technology

Coming as it does near the end of the Symposium, this paper might well be expected to sift all the reports of research and progress that have been presented by previous speakers to determine what is already known about ground water pollution and what needs to be known. Perhaps someone may perform that task when the papers are finally printed, but this writer has not had a chance to read the foregoing papers and he has just heard them as presented orally in the past 2 days hours. Consequently, this review of research needs will indicate areas that should be investigated, some of which, as you have just heard, are similar to projects already under way. Indeed, you may recall that certain projects have been terminated or concluded. That does not mean, however, that the work has been completed. As pointed out by Professor McGauhey, true research is never completed, for it always opens up many new vistas and avenues of approach for subsequent projects -- Pandora's box, as he called it.

This paper, then, is not a review of all research that has been performed or currently is being undertaken in relation to ground water pollution. Instead, it is an attempt to categorize the major areas of research that should be pursued, to increase our knowledge of this relatively untouched field. Some of the research ideas listed may have been tackled already, but more research along parallel or corollary lines is needed. We never can learn all there is to know about any subject.

In presenting the Symposium objectives, Mr. Hanson noted wisely that this meeting would be characterized more by its questions than by its answers. His prediction was substantiated as speaker after speaker raised questions and pointed to areas where much more research is needed. Indeed, there are few fields in which our ignorance is so profound. Dr. Lieberman observed that it is easier to ask the questions than to find the answers.

CATEGORIES OF RESEARCH NEEDS

Insofar as scientific disciplines are involved, the research needs in ground water pollution may be classified in the following major groups: chemical, physical, biological, geological, and mathematical. There are, to be sure, many problems that involve more than one scientific discipline, or a combination of them, such as biochemistry, geochemistry, physical chemistry, and radiochemistry. Mathematical techniques may be used in each category. Geohydrology, a study of the occurrence and behavior of water in the ground, embraces all of these areas.

Supplementing the problems related to scientific disciplines are those that involve administrative considerations and judicial expression. Previous speakers have described some of the administrative hazards and legal pitfalls. Beyond any doubt there is need for a clearer understanding of the control of ground water. Furthermore, engineers, scientists, water works officials, industrial representatives, and many others will welcome a definitive pattern of legal opinion relative to ground water pollution. It is not within the purview of this paper, however, to describe the ground water research needs in the fields of administration and law, other than to recognize that they exist and that they are important. Instead, the following discussion will be limited to the five scientific categories listed above, their combinations, and their subcategories. Finally, there will be a brief comment about the greatest need of all in ground water research today.

CHEMICAL PROBLEMS

By far the most numerous and complex problems of ground water pollution, in the opinion of this writer, are those involving chemical phenomena. There is a need to know more about the chemistry of various types of soil, for this medium is seldom inert. Indeed, the chemical content of water flowing through an aquifer is dependent to a large extent on the adsorptive, desorptive, and exchange capacity of the soil. Soil chemistry is an advanced science, but most of the effort to date has been in the realm of agriculture. Notable have been the research and publications of the staff of the USDA Salinity Laboratory at Riverside, California. Geohydrologists need to "bone up" on the work of the soil chemists and use the knowledge of this discipline to predict the effects of soil on the quality of water passing through it. Most of the work to date has been concerned with soil chemistry and water quality in the plant root zone, but many of the principles can be transposed to deeper percolating waters and confined aquifers.

Geologists classify soil in terms of its mineral analysis, e.g., percentage of mica, silica, dolomite, clay, etc. It would be useful if we readily could transpose these mineral analyses into chemical data from which the reactive characteristics of the soil could be utilized quantitatively.

Corollary to the area of soil chemistry is the need for improved and standardized methods for analyzing the adsorptive, desorptive, ion-exchange capacities, and redox potentials of various soils and the kinetics associated therewith. A field kit in a little black box would be ideal for such analyses, but until it is available these phenomena can only be measured approximately by in situ observations with field wells or by percolation through soil columns in the laboratory.

To be more specific, we need to know the rates of adsorption, desorption, and ion exchange for each chemical substance and for combinations of chemicals in aqueous solution passing through specific types of soil. To what extent, for example, will iron and/or manganese be leached from a certain aquifer by distilled water or by waters of various mineral composition? What will be the effect of dissolved oxygen, carbon dioxide, methane, hydrogen sulfide, and other gases? What is the relation of the redox potential to these reactions?

Can we predict the extent to which calcium and/or magnesium will be exchanged with sodium and/or potassium as water of a known chemical composition passes through an aquifer of known permeability and mineral analysis, but of unknown chemical properties? Dr. Kaufman presented some data on ion-exchange softening in the South Coastal Basin at Los Angeles. We need more of this type of data. What will happen to hexavalent chromates, borates, fluorides, phosphates, cesium, strontium, and other mineral ions in relation to various soils? Which ions are likely to be permanently adsorbed, and which are likely to be eluted by subsequent flow? Indeed, the entire subject of chromatographic effects in ground water behavior is a relatively unexplored field. Without a doubt many soils act as a chromatographic column with respect to the substances in certain waters, but we know very little about this phenomenon.

Nitrogen and Sulfur Compounds

Two groups of mineral ions conspicuous by their omission from the foregoing paragraph are the inorganic nitrogen compounds, namely ammonia, nitrites, nitrates, and nitrogen gas, and the sulfur compounds, specifically sulfates, elemental sulfur, and sulfides. They deserve special consideration, for they are subject readily to oxidation or reduction. What happens to nitrates that leach dowsward from heavily fertilized agricultural land or from cesspools? Under aerobic conditions, especially in the percolating waters of the zone of aeration, they may be expected to remain as nitrates; but in the absence of dissolved oxygen and in a reducing atmosphere, will they change to nitrites and perhaps even to nitrogen gas? Dr. Baars presented data from The Netherlands showing that nitrates were decreased in concentration after the dissolved oxygen was diminished. What happened to the nitrogen ions? Will these nitrogen reactions occur in the absence of specific organisms, and if not, are the necessary organisms likely to be present in deep aquifers?

Similarly, under what conditions in the soil will sulfates be reduced to sulfur or to sulfides? In what types of waters are the microorganisms commonly associated with such reactions likely to be present? Can the reactions occur in the absence of organisms, i.e., can they be strictly chemical and not biochemical?

These questions about nitrogen and sulfur compounds are especially relevant to the percolation and recharge of ground waters by organic industrial wastes and sewage. Such waters are not likely to be sterile, although the travel of microorganisms may be limited to a short distance. This brings us to the subject of biochemistry.

Biochemical Degradation

Chemical reactions brought about by biological processes have long been subject to quantitative evaluation in surface waters. In the ground, however, they are more difficult to assess, and as a result, relatively little is known about reactions rates, mechanisms, pathways, intermediate steps, and end products.

Ground water differs from surface water, insofar as biochemical degradation is concerned, in serveral important ways. First, the ratio of surface area of the soil to the quantity of flow is tremendous in ground water. This area - volume ratio will influence the rate of biochemical phenomena, for many of these reactions are accelerated by the presence of large surface areas. Second, detention periods are long, so that even the slower reactions may go far toward completion. Third, ground waters are often anaerobic and frequently under high pressure. Fourth, higher organisms are removed readily by filtration through soil, and consequently biochemical action may be limited to the lower forms or perhaps even to enzyme effects. Little, if anything, is known about the role and travel of enzymes in ground water. There is a need for quantitative evaluation of all of these factors, and perhaps others, in relation to various organic compounds and to specific types of soils.

A most urgent problem in relation to biochemical degradation involves the persistence of alkyl benzene sulfonate (ABS) and other components of synthetic detergents. As several speakers have indicated, ABS has been observed to travel through soil for considerable distances; yet 50 to 90 percent of it can be removed by the activated-sludge process. Furthermore, its half-life in surface streams has been estimated at 16 days, and along the Illinois River, the total ABS in the flowing water was diminished by 33 percent in 6.6 days of travel. With the slow velocity through ground water, ABS should be stabilized in short distances if experience from surface streams can be transposed to underground aquifers. But can it?

Is the observed persistence of ABS in ground water related to the fact that bacteria are filtered out in the first few feet of flow? What is the effect of anaerobic or reducing conditions on the stability of ABS? Can a soil be "seeded" or "acclimatized" to hasten the degradation of ABS or any other organic compound? To what extent will ABS be adsorbed and desorbed from various types of soils? Can chemical substances be added to alter these reactions? These are all questions that deserve detailed investigation.

Two-phase Systems

Thus far, this paper has been limited for the most part to dissolved substances in water. There are many problems, however, that involve the atmosphere in the interstices of soil above the ground water table or phreatic line. In accordance with the gas laws, this atmosphere is in dynamic equilibrium with the dissolved gases and certain ions in the underlying water, especially if the water table fluctuates in elevation or if it is being fed from water percolating through the overlying soil atmosphere.

The problem is brought into sharp focus by the decomposition and stabilization of sanitary landfills, as described to you by Mr. Weaver. If this organic material is below the ground water table, or if it is leached by heavy rainfall or irrigation, organic and inorganic substances will enter the ground water. Many sanitary landfills in the arid Southwest, however, are supposedly "high and dry," perhaps 20 to 100 feet above the water table, and seldom subject to leaching by rainfall or irrigation. How can such fills possibly affect ground water quality?

First of all, they undergo biochemical stabilization, although it may be very slow. We need to know a lot more about the rates of stabilization and how they are affected by moisture, temperature, composition of waste, mixing with soil, and other factors. In any event, gases of anerobic decomposition, such as methane, carbon dioxide, and hydrogen sulfide, are produced. These gases diffuse through the soil and are subject to the laws of fluid dynamics. Permeating the atmosphere of soil interstices, they eventually come in contact with the phreatic line or at least its capillary fringe. There, they go into solution in the ground water, to strive for the equilibria of Henry's Law. Although these general mechanisms can be postulated, little quantitative information is available on the actual occurrence and movement of gases through soil and their relation to the quality of water in the upper fringe of the ground water table. Furthermore, additional data are needed on the rates of diffusion of these dissolved gases downward, laterally, and longitudinally through the ground water.

Another group of problems involving the gas phase is related to the low-molecular-weight hydrocarbons, whether of natural origin or resulting from underground storage. Many fresh ground waters, especially from oil-producing areas or from regions where peaty deposits abound, have been observed to contain dissolved methane. Other hydrocarbons have reached ground waters by man-made pollution or by escape from storage.

The foregoing discussion of chemical effects in relation to ground water pollution is far from exhaustive, but perhaps it will serve to indicate the magnitude and complexity of the problems. The list of research needs could be enlarged manyfold by inclusion of the problems related to specific industries, such as metal-finishing, regeneration of ion-exchange resins, oil-field brine disposal, petroleum products, food processing, and many others. Perhaps it is well at this time, however, to consider another major scientific category.

PHYSICAL AND MATHEMATICAL PROBLEMS

The physical and mathematical aspects of geohydrology are related primarily to fluid mechanics and especially to hydrodynamics. These subjects have been investigated more thoroughly in ground water than have the chemical aspects. Fortunately, moreover, they can be adapted to mathematical analysis, within certain boundary conditions and assumptions. Yet, there are many areas of physical and mathematical research in ground water that need further exploration.

Thanks to Darcy, Boussinesq, Dupuit, Forchheimer, Thiem, Kozeny, Bakhameteff, Casagrande, Muskat, and many others, the classical hydrodynamic and mathematical aspects of ground water flow have been well developed. The work to date, however, has dealt largely with an inert liquid, a homogeneous soil, and steady state conditions. There are still many gaps in our knowledge of hydrodynamics in soil. Just a few minutes ago, Dr. Lieberman described to you many of these problems.

We need to know more about the dispersion of a pollutant as water travels through various types of aquifers. What is the extent and rate of vertical and lateral diffusion under various conditions of permeability and soil characteristics? What are the yardsticks of diffusivity in soil, and what are their approximate magnitudes? How can the parameters of longitudinal mixing of unsteady concentrations of waste be evaluated? What will be the effects and mixing of fluids of different densities? Soils are seldom homogeneous and indeed they are frequently interspersed with laminar lenses. How does such nonhomogeneity influence the classical analyses, and how does it alter the parameters of vertical lateral, and longitudinal diffusion?

It is recognized that much research along these lines has already been performed by the oil industry in connection with its water-flooding operations and by ground water hydrologists concerned with salt water intrusion. There are still many aspects, however, that deserve more detailed study, especially with respect to recharging operations by means of spreading basins or pressurized wells.

Much of the work in analysing flow through porous media involves complicated differential equations, conformal mapping, complex variables, and other mathematical procedures. It would seem appropriate, therefore, to utilize computer technology to a large extent in such work. The feasibility of automatic numerical analysis in many problems of ground water hydraulics is being investigated, but such research is still in its infancy.

Radioactivity

Three major areas of ground water research involve radioactivity. First, we need to know more about the travel of radioactive substances through soil; their adsorption, desorption, and ion exchange; their diffusion and dispersion; and their effects on the other substances in soil and water. You already have heard several references to such research at this Symposium.

Second, we need to explore further the use of radioactive substances as tracers to assist in geohydrological investigations. Which substances can be employed with minimum adsorption or chemical change and with minimum hazard to the subsequent users of the ground water? Can we take a calculated risk in the use of radionuclides in ground water that may be consumed by humans?

Third, can deep aquifers be used for the disposal of radioactive material of long half-life without danger to water supplies? What are the possibilities of cross-contamination among aquifers at various depths, especially if they are perforated by abandoned or poorly constructed wells?

Infiltration and the Mechanics of Clogging

To those of us who are interested in waste water reclamation by the recharging of ground water basins and aquifers, the problems at the interface between free water and the soil are paramount. We need to know more about the mechanics of clogging, whether it be by physical means, chemical action, or biological growth. To what extent must waste water be purified before it can be recharged through spreading basins, and to what extent for pressurized wells? What are the best parameters for measuring clogging potentials? When the interface has been clogged, what are the best methods for restoring infiltration capacity? What chemicals can be added to prolong the periods between redevelopment or backwashing of wells? Will the use of certain crops in spreading basins increase infiltration capacity, or will concomitant problems such as mosquito breeding and transpiration losses rule out such practices? What is the role of sprinkler irrigation in ground water recharge? Does it have advantages over spreading basins operated intermittently?

Soil physicists, like soil chemists, have developed their specialty to an advanced stage. Ground water hydrologists and engineers should draw heavily on the experience and literature of this discipline. Special attention needs to be given to methods by which permeability of soil may be increased, or in certain instances how it may be decreased. What chemical agents can be used to change permeability without harm to subsequent beneficial uses of the water? If these changes in permeability are produced by wetting agents or surfactants, what will be the effect on travel of other chemical substances and biological organisms? How can certain aquifers best be sealed to prevent the travel of pollution? One example of this problem is salt water intrusion along coastal regions. In other instances, portions of polluted aquifers might be sealed off to prevent the further encroachment upon unpolluted portions. How best can this be accomplished?

There are many more physical and mathematical problems related to ground water pollution. Without a doubt, each of you could enumerate several of them. Time requires, however, that we pass on to another major scientific category.

BIOLOGICAL PROBLEMS

Dr. Mallman has given us an excellent review of the state of knowledge about biological contamination of ground water, and indeed he has pointed out many areas where information is sparse or totally lacking. Empirical data have been obtained in many situations for the travel of bacteria through soils of various characteristics, but there are no experimental results on the migration of viruses in ground water. There is qualitative proof that viruses can travel considerable distances through aquifers, and several outbreaks of hepatitis have been traced to ground water. No virus epidemics other than hepatitis have been so traced.

It would appear, therefore, that considerable research is needed on viruses and bacteriophages. Do nonpathogenic forms occur in natural ground waters unaffected by human contamination? How is the travel of viruses in ground water related to the physical and chemical characteristics of the soil? Will they survive in the absence of bacteria, or are the two forms synergistic? In a given soil, will viruses and phages travel farther and/or faster than bacteria? What are the effects of syndets and other chemical pollutants on the presence, survival, and travel of viruses in ground water? How can the transmission of viruses through aquifers be prevented or minimized?

Related to the presence and behavior of bacteria and viruses in ground water are the biochemical problems dependent on enzyme action. If bacteria in contaminated water are adsorbed in the first 100 feet or so of travel through an aquifer, do the exoenzymes from those organisms move freely with the percolating water and exert their influence in biochemical degradation far beyond the limit of bacterial penetration? If so, can recharge wells or spreading basins be inoculated with beneficial bacteria that will aid in the degradation of specific organic substances during ground water travel? Can extracts of enzymes be used directly? It would appear that the whole field of enzyme chemistry in relation to the organic pollution of ground water is virgin territory for research.

GEOLOGY

It would not be prudent to terminate this discussion of research needs without mentioning the geological problems. Indeed, ground water has long been considered the realm of the hydrogeologist or geohydrologist. It was not until pollution and contamination of ground water became serious that chemists, biologists, and sanitary engineers took proper notice of this important phase of water resources. This Symposium may well serve to integrate the efforts of many disciplines in this important problem.

Before any field studies of ground water pollution can be made, a thorough geological investigation is necessary. The thickness, extent, degree of homogeneity, mineral character, permeability, and other parameters of each aquifer should be known. Such data are tedious and expensive to obtain. Methods are needed to facilitate the gathering and processing of geological information. Perhaps geophysical techniques can be perfected that will yield much of this information without penetration of the aquifers and confining strata, i.e., penetration by numerous test wells that might later cause interpollution of aquifers. As mentioned herein before, there is a need for conversion of mineral analyses to chemical characteristics that can be used for predicting the interaction of soil and water.

NEED FOR TRAINED RESEARCH PERSONNEL

In the list of scientific categories earlier in this presentation, it was noted that the paper will conclude with a brief comment about the greatest need of all in ground water research today. In a nutshell, we need trained scientists and engineers who understand the fundamental concepts of ground water and want to perform research in this field.

It is easy to enumerate scores of potential research problems, as this paper has done. It is not too difficult to outline the methodology for accomplishing many of these projects. It is probable that financial support for research projects in ground water pollution can be obtained readily from one or more sources. Physical facilities for conducting such projects are available at many universities and private institutes. The real bottleneck lies in personnel properly trained and inspired to do the work.

There is a great need for publicity to emphasize the importance of ground water in our national economy and the opportunities for stimulating careers in this field. Perhaps this Symposium will set the stage for a resurgence of interest in ground water problems.

SUMMARY OF SYMPOSIUM

W. C. Ackerman, Illinois State Water Survey

I would like to preface my attempt at a summary of this Symposium by stating that these veiws are my own - those of an individual who stayed awake, kept his ears open, and his mouth closed. I am uninstructed by our hosts and am the agent of no one. This Symposium definitely was staged with brilliant speakers, making a preconceived set of conclusions impossible.

In one regard, at least, I know that I speak for all who have come in thanking the Taft Center and the Division of Water Supply and Pollution Control of the Public Health Service for calling us together. It has been a beautifully planned and executed Conference. It has been an act of real leadership.

Director Hanson set the stage and, it seems to me, correctly anticipated the course of the Symposium when he stated that our "age is characterized more by questions than by answers." He touched on various aspects of ground water contamination that were later to be developed in greater detail. He called for facts and suggested that present research is not commensurate with the complexity of technical and administrative problems. He ventured the thought that now, 2-1/2 days later, seems a certainty: This meeting has summarized existing knowledge, has focused attention on a growing problem, and will add great impetus toward solving problems of ground water contamination.

The logic with which this Symposium had been planned became clear as we were lead deeper into our subject by Messrs. De Buchananne, Brown, and Sniegocki, who explained the geological framework and the hydrologic vehicle within which and by which contamination moves. We were reminded of the importance of geologic stratigraphy and structure and their effects on water tables, artesian conditions, and even streamflow. Sands and gravels may have excellent water-yielding qualities, but they are not efficient in taking contamination through ion exchange. Limestone is always under suspicion because of its solution channels, and although crystaline rocks may be a barrier to flow, they too can contain routes for contamination through fractures and faults.

Hydrologic factors include infiltration, percolation, saturated and unsaturated flow, and permeability. We found that contamination can result from natural recharge or, more likely, from recharge by man through irrigation, water spreading, recharge pits, and wells or from the lowering of the water table.

Mr. Hem tied geology and hyrdology together in the effects of water chemistry. Because of the slow movement of the ground water and its long contact with soild and rock, chemical equilibrium often is reached. By examples we were told about adsorption, solution and deposition, oxidation, and reduction.

Mr. Frescher gave us a direct and orderly presentation of the procedures for conducting areal ground water investigations, and by the time we went to lunch that first day, there was no doubt that geologists had made their point - that geology is the framework and the control. Beyond that it had become clear that ground water contamination requires an interdisciplinary approach and that the solution of problems will require a team effort.

In the session on types of contaminants, this Symposium reached new stature with Professor Mallman's comprehensive and scholarly review of biological contamination. He traced its history from 1854, years before the birth of the science of bacteriology, in London where contamination of the Broad Street well correctly was correlated with pollution from fecal matter. Fortunately, processes of self-purification and filtering normally limit the movement of bacteria to less than 100 feet in soil.

Dr. Mallman sounded a warning on viruses, since they seem to be more resistant and more persistent than bacteria. Our techniques are poor, and we are almost lacking in virus research data related to soils.

Professor Mallman concurred with Dr. Hanson of Wisconsin, speaking from the floor, when he pointed out that bacterial pollution can extend for great distances in limestone formations because of the lack of filtering action.

I had the feeling that Dr. Kaufman's paper on inorganic chemical contamination was all substance and was outstanding, even on this excellent program. He gave us three frames of reference: domestic drinking water, irrigation, and industrial. For drinking water we universally apply the well-known drinking water standards, even though the support for some of these is rather tenuous. In agriculture reasonable well-defined limits are established, and for industry the limits are highly variable, depending upon the use.

For radioactive substances some contend there is no threshold value. Dr. Kaufman's statement was convincing, though, that there is no evidence of radioactive pollution of ground waters from man-made sources other than in limited areas of AEC reservations where the sources are monitored by vigilant professionals.

Dr. Kaufman offered two solutions to inorganic pollution: dilution in surface streams or deep injection. He also offered a novel solution that just might become a practice in years to come - abandon our water courses and permit them to become agricultural sewers and then transport fresh water over great distances.

Mr. Middleton, speaking for himself and Graham Walton, described the newcomer in the field of contaminants, organics. Most common offenders are gasoline, oil, detergents, and phenols. As recently as 1952, only a few states recognized organics as a problem. Now this problem is full blown, but knowledge is scarce. This is surely an area that will require concerted research and action.

A feature of organic pollution is its persistence; it has been known to travel 15,000 feet over a period of 7 years. Although it may first be detected as foam or by taste and odor, the strongest evidence is identification of specific substances in the ground water - traced back to the source.

In the closing paper on the first day we focused on Dr. Baars the admiration that we all hold for the people of the Netherlands. These people, who live on the brink of disaster, with the sea at their door and the contaminated Rhine at their back, are the master managers of water. Dr. Baars made an important contribution to the Symposium and demonstrated by his well-documented paper how these people can develop 77 percent of their water needs from underground sources, despite large odds, by research, careful planning, and vigilant operations.

On Thursday morning this Conference documented its own case, that the problems of ground water contamination deserve greater attention. This was done by 12 fascinating case histories. I cannot attempt a summary of these individual incidents, but I would like to record some personal impressions that stand out as I reflect on these happenings.

Most of these case histories were known in a general way to all of us, but it seems to me now that the incidents were actually more severe than had previously been realized. I am thinking of Minneapolis-St. Paul and Long Island, particularly.

I was reminded by the apparently bottomless pits at Tieton, Washington, of how easily we fall into the pattern of the old adage, "out of sight - out of mind." The story of infectious hepatitis in Posen, Michigan, with its private wells and septic tanks in shallow soil on limestone prompts me to say, "How can we be surprised when the obvious happens?"

From the story of the oil field at Greensburg, Kentucky, we had an example of that for which we in America have been famous -- wanton exploitation of our natural resources with a profit motive. We also learned that 600 guilty people can be right because it is not possible to prove any one of them wrong.

The vast quantities of our solid wastes, as described by Leo Weaver, took on new meaning last night when Dr. Nelson Glueck described how ancient cities were buried by their own rubble. Of more immediate concern is the organic, inorganic, and bacterial pollution of ground water that can result from improperly located dumps and land fills.

I was struck by the fact that we professionals have generally not been the ones who initially uncovered ground water contamination. More likely the revelation stemmed from citizens' complaints of taste and odor, or foam, or crop damage, or sickness.

Strong feeling was certainly present at the Symposium that now is the time to stand up and count the worth of our underground resource - not as a burial ground for our unwanted and untreated wastes, but as all water resource that this country must manage for use and reuse into the indefinite future.

Our research tools and research information are weak in the areas of organic chemicals, viruses, and radioactivity. We country boys may feel that the Taft Center has all the answers, but the people who are that Center don't share this easy view.

It seems to me that lagoons and septic tanks got black eyes at this Symposium. Unless carefully designed and well spaced, these devices are probably passing practices in urban and metropolitan societies.

Contamination of ground water by radioactive waste is limited to a few sites on government reservations, where it is continuously monitored by competent professionals and therefore does not represent a public hazard.

We have found that there is no substitute for good chemists, good geologists, good bacteriologists, and good engineers - and this means more education.

We have learned that there is no substitute for public support for what we know is right - and this takes a lot of education.

Whether we can sustain a permanent irrigation agriculture seems to be an open question. As with the ancients, will accumulated soil chemicals finally engulf us?

The question of whether synthetic detergents are a curse or a blessing, or a mixed curse, or a mixed blessing, in ground water contamination was evident. Perhaps the answer depends on one's point of view, but the presence of these organics has aroused public action; this much surely can be said.

One would judge that the actions of FHA are controversial in this area of ground water contamination. Far be it from me to attempt expressions of a consensus of this Symposium on the matter. But this much can surely be said: The FHA has acted with courage in what it believes is right. We might note, also, the impact, both and direct and indirect, that the actions of such an agency have on our urban and suburban developments.

I wonder if Mr. Muegge of Wisconsin didn't hit the nail on the head when he said that we need "publicly supported regulation." Implicit in those three words is much of what we have been speaking. It means research and facts, it means education, it means criteria and standards, it means enforcement, and it means management of natural resources for consistent, multipurpose and beneficial use.

DISCUSSION

Chairman: B. B. Berger

Mr. Lester M. Klashman of the Public Health Service asked Mr. Arthur E. Bruington two questions, both concerned with the artificial recharge of ground water by the Los Angeles County Flood Control District. On what basis are consumers charged for the water? How much recharged water is lost through evaporation and in other ways?

Mr. Bruington replied that at present there are two methods of collecting money for financing the recharge operations. When the need for spreading imported water became urgent during the early 1950's, portions of the District that were directly affected were formed into zones and the property owners were taxed on an ad valorem basis at a rate not to exceed 5¢ per $100 assessed valuation for purchase of water. The second method, which was begun this season, involved the formation of a district with power to levy a pumping assessment against each water user. For this year the rate is $3.19 per acre-foot (1¢/1000 gal), and for next year it is expected to be $5.75 per acre-foot (1-3/4¢/1000 gal).

In answer to the second question, Mr. Bruington noted the rates of delivery of the water are so great that no accurate determination has been made of the evaporation loss but that it probably does not exceed 1 or 2 percent.

Professor Jack McKee commented on costs of water in southern California. The operating costs for pumping water to Los Angeles County from the Colorado River are about $12 per acre-foot. If this water is softened and filtered, it costs the purchasing agency about $25 per acre-foot. If all costs, such as amortization of the aqueducts and pumping stations are included, the true total cost is about $45 per acre-foot (14¢/1000 gal).

Colorado River water has a total dissolved solids content of about 700 ppm. Sewage water in the San Gabriel Valley, which originates from Colorado River water plus some natural waters, contains around 800 to 900 ppm total dissolved solids. This sewage is being discharged to the ocean, even though it is still fresh water. It can be treated rather thoroughly in an activated-sludge plant at a cost, including plant amortization, of about $9 per acre-foot, much less than the $45 acre-foot it costs to import water into the Los Angeles area. To recharge this reclaimed water into the ground and then repump it will cost an additional $5 per acre-foot. (The implied total cost of such reclaimed water becomes $14 per acre-foot or 4.3¢/1000 gal.) From recent literature one can see that people who are promoting the desalination of sea water have great hopes for producing fresh water at a cost of $1.00 per 1000 gal. In Los Angeles County we are hoping to recharge the ground water with treated sewage and reclaim is as ground water at a cost of less than 5¢ per 1000 gal. Reclamation of sewage appears to be far more practical and economical than desalination of sea water.

APPENDIX

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